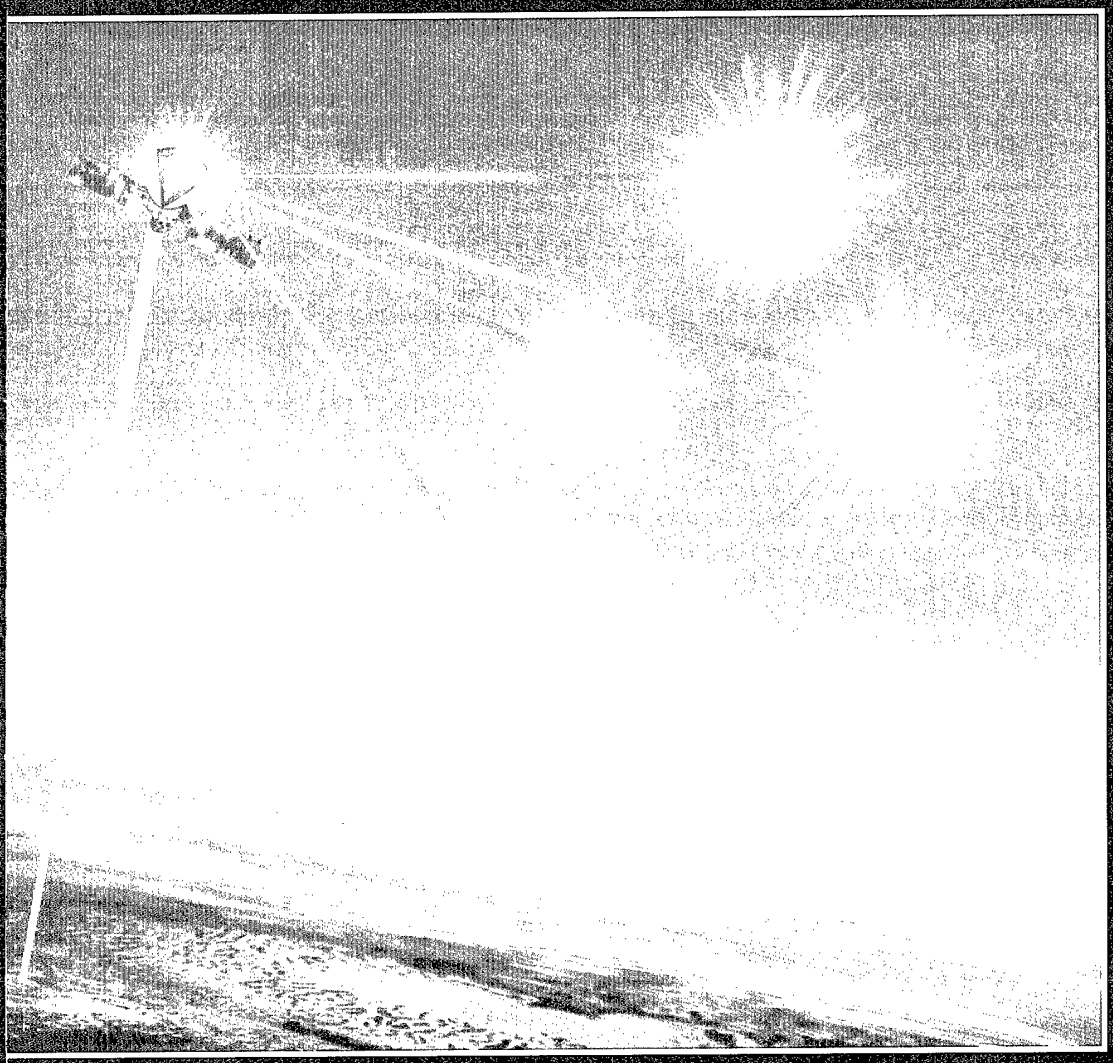
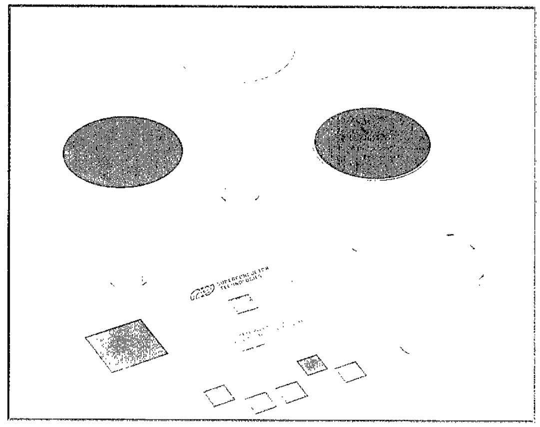
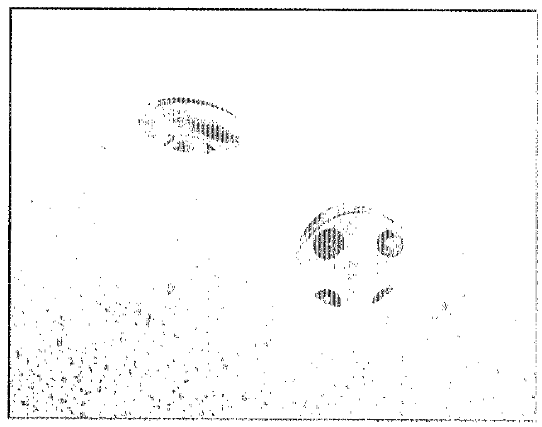
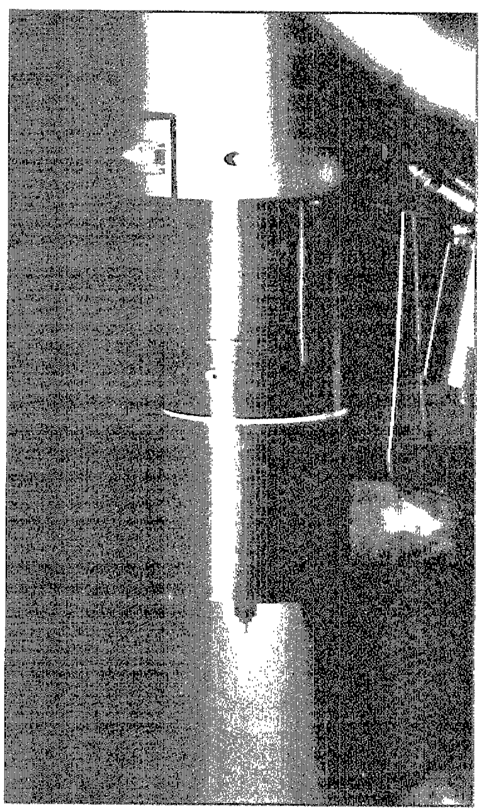


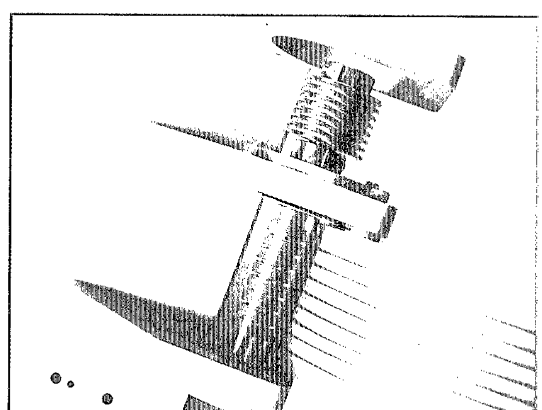
TECHNOLOGY APPLICATIONS REPORT 1993

BALLISTIC MISSILE DEFENSE ORGANIZATION









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TECHNOLOGY APPLICATIONS REPORT 1993

BALLISTIC MISSILE DEFENSE ORGANIZATION

FOREWORD

The United States is now selling products and services in a global economy that is dynamic, complex, and increasingly competitive. To maintain U.S. prestige as a world-class innovator, American business leaders and entrepreneurs must manufacture the highest quality products at competitive prices. The Ballistic Missile Defense Organization (BMDO) recognizes that one of the most efficient ways to incorporate innovation into the nation's economy is to transfer federal technology—developed by matchless expertise—into American businesses.

BMDO's Technology Applications program has been a leader in federal technology transfer for seven years, and to solidify our leadership we recently formed a new partnership with the National Technology Transfer Center (NTTC). Under this agreement, the NTTC will operate the Technology Applications Information System, our on-line database, and provide other technology transfer and commercialization support, including many of the activities described in this report.

Like the Technology Applications Office, the NTTC is committed to improving the technological strength of American businesses. The success stories in this report are fruits of that commitment. The future holds even greater promise as more technologies mature and more people use our services. So, as you read this report, keep in mind that a staff of technology transfer specialists is only a phone call away at (703) 518-8800, ext. 500. They will be happy to answer any questions about a specific technology in this report or any other services we can provide.

Sincerely,

NICK MONTANARELLI
Deputy Director for Technology Applications
Ballistic Missile Defense Organization

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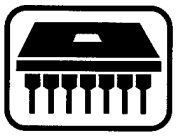

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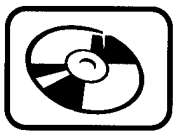

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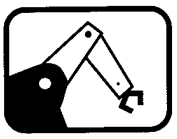

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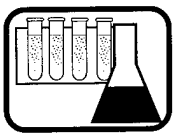

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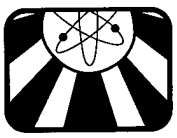


INTRODUCTION

Defense Conversion and Technology Commercialization at BMDO

In light of the Cold War's end, industries, laboratories, manufacturers, and government agencies are striving to convert defense research into commercial products. Yet these efforts echo the not-so-new activities of the Strategic Defense Initiative Organization (SDIO), which has recently changed its name to the Ballistic Missile Defense Organization (BMDO). (See the sidebar on page 2.) By whatever name, this organization has played a dynamic role in commercializing technologies for several years. Over the years, BMDO has developed many tools for transferring defense technology, answering some of the "how do I convert my laboratory?" questions that administrators in the defense industry are currently asking.

The main thrust of BMDO has always been to provide superior defense against ballistic missile attacks for the United States and our allies—a mission represented by years of hard work and technical expertise in R&D. However, BMDO recognized from the beginning that many of the technologies R&D experts were developing could also provide breakthroughs—sometimes crucial ones—needed in civilian life. This recognition spawned its Technology Applications program.

Over the years, the Technology Applications program has helped BMD-driven innovations contribute to the manufacturing, energy, environmental, biomedical, and electronics industries, to name just a few. These innovations have provided people with time-saving, money-saving, energy-saving, and sometimes life-saving developments. And in the process, the Technology Applications program has been able to boost business for small firms by supplying technical and commercialization information, as well as contacts. Small businesses have been able to use this information as a foundation for new products to be sold in the commercial marketplace or to improve existing products.

"Diversity and accessibility are the keys to a successful technology transfer program. Our program is successful because we make an abundance of business and technical information available through multiple channels," explains Nick Montanarelli, Deputy Director of the BMDO Technology Applications program.

The Technology Applications program administers several key outreach activities that help commercialize technology developed by BMDO. Examples of outreach activities include producing and disseminating publications, facilitating face-to-face meetings with businesses interested in commercialization, and maintaining an extensive on-line database network for commercial users.

To reach those who want to use BMDO technology, the Technology Applications program publishes the ***BMDO Technology Applications Update*** and many other documents, including this report. The ***Update*** is a free newsletter to spread the word about BMD technologies currently moving into the commercial marketplace or having potential commercial applications. Over 7,000 newsletters are circulated quarterly to anyone interested in finding new uses for BMD technology: executives of small

1993 Marks Turning Point in Ballistic Missile Defense

In May 1993, the Strategic Defense Initiative Organization changed its mission and was renamed the Ballistic Missile Defense Organization to reflect the nation's changing needs after the Cold War. BMDO now focuses on three, more limited, objectives:

- Development of more capable theater missile defenses
- R&D for deploying ground-based systems to defend the nation against limited long- range ballistic missile attacks
- Development of advanced follow-on missile defense technologies.

With BMDO's narrower approach in developing advanced technology, the Technology Applications program now plays an even more vital role in technology transfer. The Technology Applications program not only transfers ongoing BMD-funded research; it also maximizes the benefits of research that is no longer a BMD priority, but that could be used by other government organizations and the commercial sector.

and large businesses, R&D scientists, media contacts, and government officials in technology. The ***Update*** brought 5,900 inquiries in 1992. A survey of 900 of those respondents showed that at least 54 collaborations —including joint ventures, licenses, product purchases, and joint proposals —have resulted from the access to BMD technology that the ***Update*** provides.

One of the many examples of the ***Update's*** impact relates to a company that was mentioned in a software article in the newsletter. The company found the exposure to be so valuable that it marked the mention of the ***Update*** on a milestone chart that plotted the company's commercial success.

Other companies have noted similar experiences from the ***Update***. A mention in an article on silicon carbide nonvolatile random access memory (RAM) devices (see page 17) resulted in over 41 requests for further information, as indicated in an enthusiastic letter written by James Cooper, Jr., a Purdue University researcher on the project. Nearly half the responses were from corporate executives—an audience with the resources to launch such technology.

BMD technology spans many directions over different business sectors. It is essential, therefore, that the program maintain close contact with the media and professional and trade associations. With deep-rooted channels of communication to their members, these sources strengthen BMDO's technology commercialization network. The Technology Applications program maintains strong working relationships with 15 professional and trade associations—and the number is continually growing. In addition, roughly 60 articles from media sources mentioned either BMD spinoff technologies or the Technology Applications program in the 15 months following January 1992.

At least 54 collaborations–including joint ventures, licenses, product purchases, and joint proposals–have resulted from the access to BMD technology the ***Update*** *provides.*

The Technology Applications program also provides abstracts of BMD technologies on-line through the Technology Applications Information System (TAIS) database. Over 23,000 individuals and businesses in the United States currently have access to this database, which is continually updated to include new developments in BMDO-funded research. The TAIS also describes contracting opportunities from the Innovative Science and Technology (IS&T) research program; Small Business Innovation Research (SBIR) program; and Manufacturing Operations Development and Integration Laboratories (MODILs). This database is a free service open to American corporations and the general public, 24 hours a day, 7 days a week.

Besides a vigorous program of informing the public about BMD technology, the Technology Applications program goes a step further and educates BMD researchers in the vagaries of commercialization during Technology Applications (TA) Reviews. These brainstorming seminars allow companies with BMD projects to candidly discuss with

volunteer experts issues that they encounter in commercializing their products. These experts provide BMD researchers with key contacts, new business approaches, and other important commercialization tips.

There are few qualifications for presenters at these TA Reviews. They must have received funding from BMD and they must be interested in finding commercial markets. TA reviewers are usually experts in the addressed technology area. They also have been involved in a variety of processes such as intellectual property protection and licensing, government or commercial R&D, consortia, or public/private partnerships. Usually TA reviewers have been through some sort of transition in the R&D process (such as a move from government R&D to commercialization).

Many success stories have evolved from TA Reviews, including several start-up companies. For example, Dr. Lambertus Hesselink, a researcher at Stanford University, presented information at a Materials TA Review. Hesselink discussed technology that could store holographic data and provide reconfigurable interconnects for computing and communications (see page 26). The TA Review was so effective that he left the table with an idea to start his own company—which he did. In 1991, Hesselink formed Optitek, and based on this BMD-funded technology, is participating in a consortium with major industrial partners on a multimillion-dollar R&D contract with the Advanced Research Projects Agency.

Dr. Steve Williamson, a researcher from the University of Michigan, presented information at a TA Review on an ultrafast photodetector, developed under BMD funding at the Ultrafast Science Optical Laboratory (see page 29). In March 1992, he formed Picotronix, Inc. (Ann Arbor, MI) as a result of feedback from a TA Review. Picotronix's BMD-funded technology—the fastest photodetector in the world—has strong potential for optical communications, transportation, 3-D imaging, and medical diagnostics.

Success stories like these two, and the others that follow, provide important case studies in how defense research can also contribute to the nation's economic welfare. They point the way for others now trying to make the same transition and show the skeptics that defense conversion can work. All of these stories, though, serve as more than a touchstone for the defense industry; they also provide new opportunities for American business. After all, commercialization is a fragile process, and today's start-up companies still need help introducing tomorrow's products.

The Technology Applications program goes a step further and educates BMD researchers in the vagaries of commercialization.

Demonstration Projects Jump-Start Technology Transfer

Sometimes technologies with strong commercialization potential require a more focused approach to technology transfer than the Technology Applications program's regular activities can provide. As a result, the Technology Applications program has started a series of demonstration projects that accelerate commercialization and provide new models of how to transfer technology. Ongoing and recently completed demonstration projects include:

State Economic Development

This project is designed to commercialize BMD-funded technologies in the State of New Mexico by combining the expertise of BMDO, the State of New Mexico Economic Development Department, the University of New Mexico School of Business, Sandia National Laboratories, Los Alamos National Laboratory, and the Air Force's Phillips Laboratory. In the process, the project will demonstrate a model for technology transfer with the following elements:

- Participation of business schools in evaluating new technologies
- Expeditious development of commercialization strategies by technology developers
- Involvement of state and other economic development organizations
- Networking of each organization's capabilities to commercialize R&D activities.

In the project, the School of Business at the University of New Mexico conducted market analysis on 12 BMD-funded technologies with strong commercial potential, a list reduced from 30 original candidates. Based on the results of the study, three commercially viable technologies with the strongest potential have been selected for further action to develop and implement commercialization strategies. A widely available final report will document the model.

Superconducting Magnetic Energy Storage (SMES) Technology Assessment

In this project, the Technology Applications program analyzed SMES technologies for their commercial potential. (SMES is a system that stores energy in a magnetic field produced by circulating current in a superconducting coil.) Possible uses of SMES technology include utility load leveling, electrical stabilization, and satellite energy storage. As part of this assessment, the Technology Applications program has written a 57-page technical report that documents the SMES program innovations and assesses potential spinoffs from the SMES system. The report evaluates potential spinoffs from components developed for SMES and identifies R&D opportunities that have been created through SMES research. The Technology Applications program is also producing a shorter brochure that will increase public awareness of SMES technology and its potential spinoffs.

Civilian Applications of BMD Accelerator Technology

In a similar project to promote commercialization, BMD is preparing a technical report on its contribution to state-of-the-art accelerator

technology. Cancer radiation therapy, transmutation of nuclear waste, and detection of narcotics and chemical explosives are only a few of the many potential applications for this technology. This report will feature the present and future payoffs from investments in the accelerator program. It will also show the coupling between BMD technology and accompanying applications.

Medical Research Technology Transfer

This two-phase project reviewed findings from medical research through the BMD-funded Medical Free-Electron Laser (MFEL) program. Free-electron laser technology could be used in numerous medical applications such as AIDS treatment, blood purification, and detection of malignant tumors. Two case studies have been written based on the status of the MFEL programs at Massachusetts General Hospital and at the Stanford Medical Center. The case studies have been developed to create a technology transfer model that can be used to help commercialize government-sponsored medical research in other MFEL organizations.

Business Trade Show Experiments

Because marketing is so important in the commercialization process, the Technology Applications program provided assistance to exhibit high-potential, BMD-funded technologies. BMD has assisted a small company in exhibiting an accelerator at a trade show for nuclear medicine. The technology was previously funded by the BMD Positron Emission Tomography (PET) program. (PET could serve numerous applications such as cardiology, neurology, and oncology.) Similar projects may be pursued in the near future.

FLC/BMDO Small Business Linkages — BUSINESS GOLD

BUSINESS GOLD is an on-line database designed to provide up-to-date information about new federally funded technologies with strong spinoff potential. Businesses can use this information to invest in state-of-the-art technologies that can give them the edge in manufacturing and selling high-quality, innovative products. Businesses can also use the database as a channel for initiating R&D business agreements such as Cooperative Research and Development Agreements (CRADAs). This effort to move technology from the laboratory to the commercial marketplace improves American businesses, and strengthens the nation's ability to compete in the international marketplace. BUSINESS GOLD provides information about the following:

- New federally funded technologies
- Federally funded business and grant opportunities
- Federal- and state-sponsored technical and business assistance services
- Federal research and technology licensing opportunities.

BMDO, the Federal Laboratory Consortium for Technology Transfer (FLC), and the Department of the Navy sponsored the first two phases of development for BUSINESS GOLD. The National Technology Transfer Center (NTTC) now offers BUSINESS GOLD on-line, making this effort in itself a spinoff from the BMDO Technology Applications program. For more information on how to access BUSINESS GOLD, contact the NTTC's toll-free gateway service at (800) 678-NTTC.

A Note About BMDO's Technology Programs

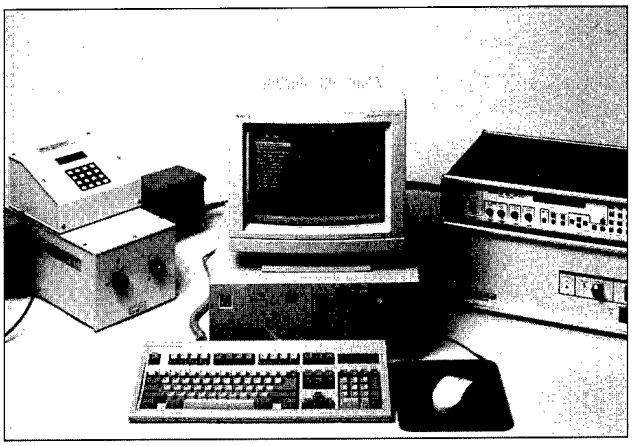
In addition to developing technology for theater missile defense (TMD) and national missile defense (NMD) systems, BMDO sponsors broad-based, long-term R&D to dramatically reduce the cost and improve the capabilities of ballistic missile defense systems. This research is managed by BMDO's Innovative Science and Technology (IS&T) Directorate, which funds research at universities, national laboratories, and in industry. To nurture infant technologies needed for BMD, the IS&T program sponsors research at a more fundamental level than other programs. While the risk is higher with this research, the payoff can be much greater—both for BMD and commercial use.

As part of the IS&T program, the BMDO Small Business Innovation Research (SBIR) program has a similar focus. BMDO's SBIR program provides small businesses with seed money to develop innovative ideas into products. SBIR contracts are divided into two phases, both of which are awarded competitively and based on three criteria (listed in order of importance):

- Degree of innovation
- Payoff to BMDO
- Commercial potential.

In Phase I, BMDO awards about $50,000 to study the feasibility of an idea that supports BMDO. Phase I projects can then compete for Phase II contracts of around $500,000 to develop the ideas into prototypes. (Awards can be higher in both phases.) Small businesses can use their SBIR Phase I and II results to develop commercial applications with other sources of funding.

ASSORTED SPINOFFS



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Spotting, tracking, and destroying ballistic missiles is a remarkably complex task. To get some idea of just how complex, consider this: A ballistic missile travels at roughly 30,000 MPH. As the missile races through the sky, a mechanical eye must focus on this missile with pinpoint precision, straying only a few millimeters while looking from miles away. And to top it off, a computer brain must take that information and guide an interceptor to the target, adjusting its direction several times within the span of a second.

The complexity of the task can be frightening, especially to the business world. "All I want," you may respond, "is a new tool to keep my manufacturing line from shutting down once a month." When broken down into more simple components, though, a BMD system can solve many such day-to-day problems. This process of relating complex technology to your everyday needs is the job of the BMDO Technology Applications Office.

How does one begin breaking down such a system so that others can use it? With a universe of different viewpoints, everyone will try different approaches. As you read about technologies in the materials section of this report, you may find uses in optics, manufacturing, or microelectronics; or while reading the microelectronics section, you could find uses in health, materials, and optics. The list of crossovers could fill the page.

This is a good thing. The whole point of technology transfer is that borders should be crossed. Human creativity will always defy rigid organization—all it needs is the right spark. So as you read this report, have fun, and remember: Your creativity can be worth a lot of money.

New 3-D Displays: Coming at Ya!

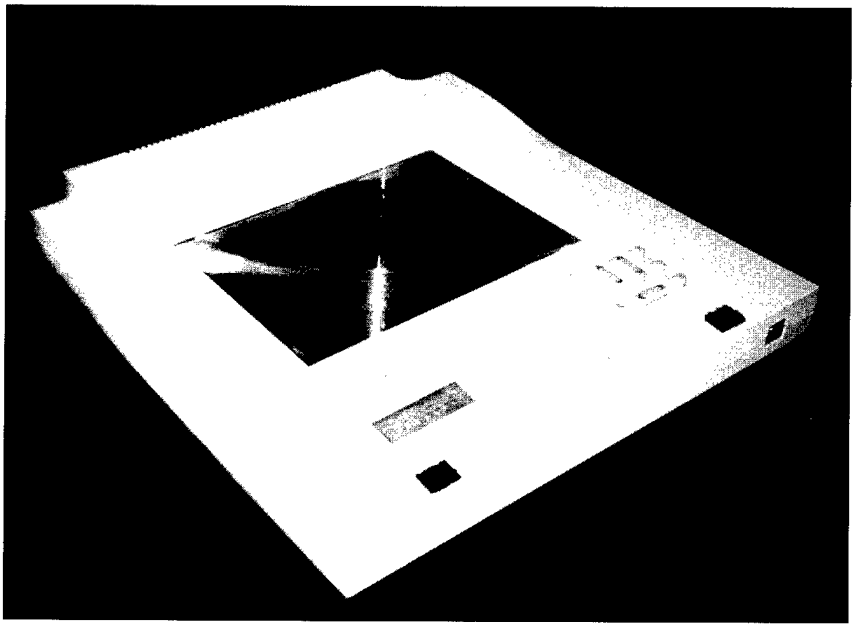
Imagine the jolt of a movie monster's hand reaching at your face—but you don't get a headache from poorly aligned 3-D shots. Or how about 3-D printouts from your computer? Or doctors looking at more realistic 3-D x-rays? With technology developed by Reveo, Inc. (Hawthorne, NY), 3-D visual displays may soon be available in any imaginable format.

Reveo's 3-D imaging technique, known as Multi-Mode Stereoscopic Imaging (MMSI), makes high-quality, color stereo images available in a variety of display formats, including electronic video and computer graphics, at an affordable price. MMSI also can produce both hard-copy and projected images, in both static or moving pictures. Furthermore, it allows viewing either with or without glasses. With 3-D glasses, images can be viewed from any angle. Without 3-D glasses, images can be viewed from a specified distance and direction.

Reveo developed this technology under BMDO SBIR contracts to build a stereo printer, display, and camera. BMDO is interested in the technology to view missiles, decoys, and other battlefield situations in 3-D. Besides the endless entertainment spinoffs of MMSI, the technology could be used in training simulators, medical diagnostics, scientific analysis, cartography, and design architecture.

So far, Reveo has demonstrated a prototype of a hard-copy printer and is selling the world's first 3-D stereoscopic projection display. Reveo is also developing a single-lens, stereo video camcorder; an electronic color stereo printer; and a 3-D graphics display monitor—all future additions to the company's product line.

In addition to hardware for MMSI systems, Reveo plans to develop an entire family of stereo films and film processing products. These films could be applied in photographs and transparencies, video display terminals, projection screens, and printers.



Above *The world's first 3-D stereoscopic overhead projection system, which Reveo, Inc. recently introduced to the market.*

MMSI Compared to 3-D State of the Art

In general, 3-D images are produced by obtaining two images ("left" and "right") of the same scene from two different points, so that you can perceive the relative distances of objects in space. MMSI shows these images using a μPol™ array, which simultaneously projects two digital images by a process called polarization encoding. In this process, an MMSI system transforms incoming unpolarized light into two perpendicular polarized states: P1 and P2.

The μPol™ array weaves thousands of P1 pixels, which show the left image, with thousands of P2 pixels, which show the right image. This arrangement allows the μPol™ array to merge left and right information on the same viewing area.

In contrast to previous 3-D systems —which showed the left image and the right image sequentially in time—Reveo's system arranges the left and right images spatially. Because it processes images spatially, MMSI eliminates the flicker common to sequential techniques, which means it can be used for video and television. MMSI also costs less than previous technology because it eliminates the shutter and additional electronics required by sequential techniques.

Another 3-D imaging technology, holography, produces extremely realistic 3-D images, but only static images with limited color capability. In contrast, binocular stereoscopy, the technology that uses the familiar red and green glasses of 3-D movies, works well for video and movie projection images. Unfortunately, it is complex and costly to make hard-copy printouts using the technique. Binocular stereoscopy also has a limited field of view, and when misaligned, causes headaches and nausea.

Sensor Scoops Data by the Handful

When shoveling sand, it's faster to scoop a handful than to pick it up grain by grain. Likewise, when measuring plasma temperature, it's better to obtain data from many points at once than to look at it point by point. Using improved spectrometers and detectors, the University of Texas at Arlington (UT-Arlington) has helped develop a multi-input sensor system that, unlike other sensors, can "scoop" many data points at once.

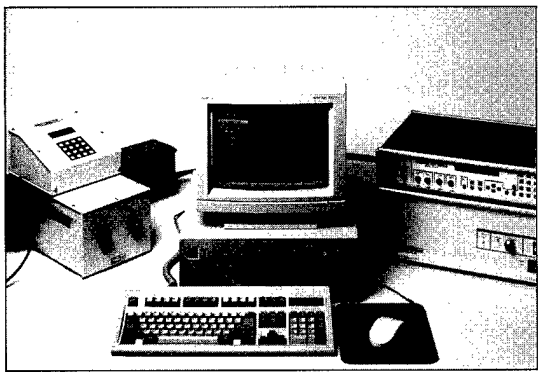
UT-Arlington developed this system to evaluate the performance of railguns for BMDO. In this project, researchers needed a detector that could measure the temperature of the plasma armature (the ionized gas inside a railgun that propels projectiles forward) at many points within the railgun. The system can also monitor plasmas used in jet engines, rockets, fusion reactors, and semiconductor manufacturing processes. In addition, the system design can be used in any sensor system that requires multiple sensor measurements. As such, it offers a cost-effective way of taking simultaneous readings through one calibrated sensor.

To obtain the same data with previous sensor systems, researchers had to repeat an experiment several times or buy more than one photodiode array (PDA), a detector used in conventional sensor systems.

Repeating an experiment, though, is often impossible because microscopic conditions in the plasma change before a shot can be repeated. Also, the cost of a PDA usually prevents systems from using more than one of these detectors. Furthermore, multiple PDAs must be carefully calibrated. With a multi-input sensor system, though, this calibration is no longer needed, resulting in more reliable data and easier data analysis. The system also costs less to produce and use.

Chromex, Inc. (Albuquerque, NM), a subcontractor to UT-Arlington in this project, now markets a Parallel Spectroscopy™ system used in manufacturing to monitor the plasmas that etch semiconductors; in the lab it has a number of other research uses. Chromex also plans to market the system, or similar systems employing Raman spectroscopy, for industrial process monitoring and control in chemical, plastics, and pharmaceutical processing. One such system, Raman One™, won a 1993 *R&D 100* Award (given by *R&D Magazine*) as one of the 100 best new products of the year.

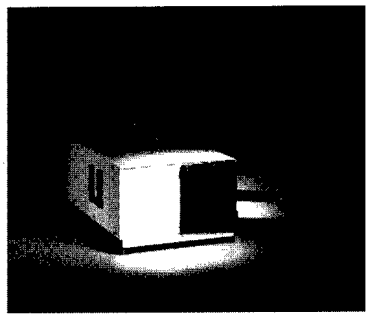
Princeton Instruments (Trenton, NJ), another subcontractor to UT-Arlington, markets components used to build multichannel sensor systems. Princeton has sold these components to about two dozen research houses, which have used them to build their own multi-input sensor systems.



Left *A multichannel sensor system built from components marketed by Princeton Instruments.*

How the Multi-Input Sensor Came to Be

To develop a multi-input sensor system, a new spectrometer had to be developed that could resolve each spectral input along the vertical axis, without destroying spectral bands along the horizontal axis. By developing toroidal mirrors that correct the vertical image, Chromex, Inc. was able to build such a spectrometer.



Above *Chromex, Inc.'s Parallel Spectroscopy™ system, developed as part of a project to evaluate the performance of BMDO railguns at the University of Texas at Arlington.*

The system also required high-quality, low-cost, charge-coupled device (CCD) cameras to detect these images. CCDs can record optical information row by row, allowing researchers to read optical information from multiple positions in the focal plane of the spectrometer. CCD-based detectors also offer very low noise, high quantum efficiency, high dynamic range, and good readout speeds. Furthermore, researchers can change the configuration of CCD detectors to best suit a particular application.

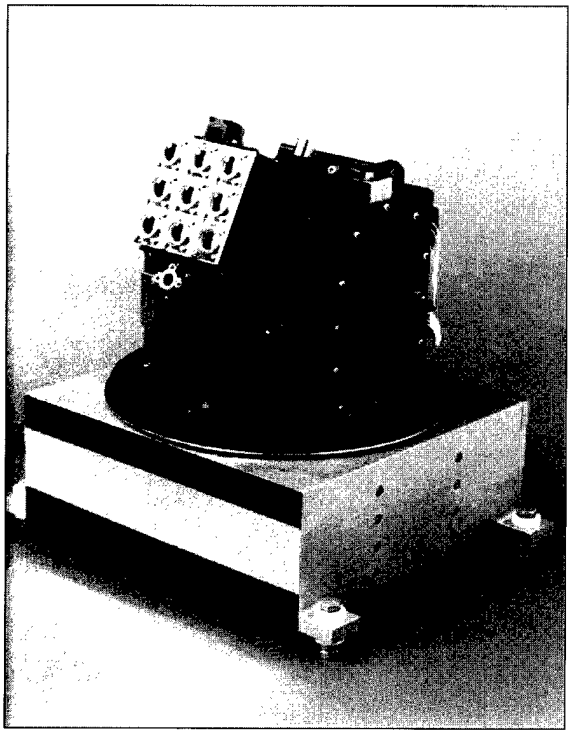
Princeton Instruments designed the CCD detectors for the system developed at UT-Arlington. UT-Arlington, in turn, contributed expertise in data processing and user requirements to make this a viable system for measuring plasma temperatures.

BMD Spectrometer Helps Environment

Recent concerns over global warming and the depletion of the ozone layer have begun to shape environmental and energy policies in the United States and abroad. Unfortunately, we do not have enough data to fully understand what we should do about these concerns. BMD technology, though, may soon help change this situation.

While designing a spectrometer to measure how BMD laser systems would travel through the atmosphere, BMD researchers realized this device could also gather valuable data about global warming and ozone depletion. All they needed to do was add a few extra capabilities that cost relatively little. For BMDO laser propagation studies, the spectrometer needed to acquire data at two wavelengths. By adding the ability to detect light at seven more wavelengths, BMDO built a $2 million spectroscope for its Polar Ozone Aerosol Measurement (POAM II) that provides environmental monitoring capabilities rivaling those of a $20 million spectroscope. POAM II designers further reduced costs by "hitching a ride" on France's SPOT 3 satellite, allowing BMDO to pay only a portion of the launching cost—the most expensive part of deploying space-based systems.

Many key players are involved in the POAM II program. The University of Wyoming (Laramie, WY) developed the original concept for POAM, while ThermoTrex Corporation (San Diego, CA) integrated the hardware and electronics for the system. In addition, the Naval Research Laboratory is managing the science program and will be involved in interpreting the data. Other key players include the Air Force Space Test Program, which arranged POAM II's journey on the SPOT 3, and France's National Center for Space Studies, which integrated the spectrometer on the satellite and launched the satellite.



Left *The POAM II Spectroscope. This device provides environmental monitoring capabilities rivaling those of spectroscopes ten times as expensive.*

How POAM II Works

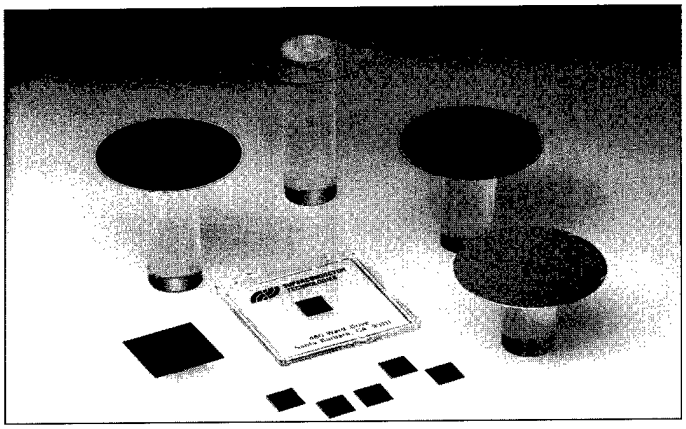
By measuring the amount and frequency of sunlight reflected off the atmosphere, POAM II will provide the first vertical profiles of the atmosphere's concentration of ozone, oxygen, aerosol, nitric oxide, and water vapor over the North and South Poles. POAM II can also provide information about atmospheric temperatures. This information is needed for atmospheric modeling and will contribute to our understanding of the physical chemistry of the atmosphere.

Currently aboard France's SPOT 3 satellite, POAM II passes near both poles 14 times each day in a sun-synchronous near-polar orbit. The POAM II spectroscope collects atmospheric data just before the satellite rounds the North Pole—which is always at the satellite's dawn—and just after it rounds the South Pole—which is always at the satellite's dusk.

Rather than viewing the atmosphere straight down towards earth, the spectroscope views the atmosphere horizontally, with its focus grazing across the tops of the North and South Poles, 12 to 60 kilometers above the earth's surface. In this way, the spectroscope can measure all the layers of the atmosphere.

All data collected is calibrated against data obtained from viewing the sun against the black background of space. Methods for comparing atmospheric data to other data against the black background of space are referred to as solar extinction techniques. By combining specific frequencies of light, certain elements can be detected using these techniques.

BMD Superconductor Technology Goes Commercial



Above *STI's high-temperature superconductor (HTS) products, developed with the help of BMD-sponsored research. STI also sells custom HTS components and assemblies, a line of cryocooler products, and foundry services.*

Superconductor Technologies, Inc., or STI (Santa Barbara, CA), has built a $5.5 million business around findings from BMD-funded research on high-temperature superconductor (HTS) thin films (see sidebar). One spinoff from STI's BMD-funded R&D is a communications product line known as MicroLoss®. MicroLoss® products include Superconducting Thin Films, Superconducting Microwave Resonators, Superconducting Custom Design Kits, and Hi-Q Superconducting Microwave Resonators (2 to 35 gigahertz). STI also sells custom HTS components and assemblies, a line of cryocooler products, and foundry services. In 1992, STI sold $300,000 in products to commercial businesses and an additional $300,000 in products to various federally funded research groups. As a result of this success, STI recently sold $15 million in stock in an initial public offering.

The BMDO SBIR program supported this research because HTS thin films could improve the performance of BMD satellite communications. Other uses of these HTS thin films include a broad range of microwave- and microelectronic-related applications such as radar, communications, biomedical imaging, computer workstations, and electronic warfare.

In further research, STI is collaborating with consultants from the University of California-San Francisco Radiology Imaging Laboratory to fabricate and test HTS magnetic resonance imaging (MRI) coils. MRI is a soft tissue imaging technique used for brain scans, mammograms, and musculoskeletal scans. Initial tests indicate that the signal-to-noise ratio of STI's HTS coils is 30 percent better than copper coils cooled in liquid nitrogen. Furthermore, STI is developing small pickup coils under a Phase I SBIR contract with the National Institutes of Health that should reduce the cost of MRI equipment.

Using research findings from previous BMDO SBIRs, STI also is participating in a major R&D project for the Advanced Research Project Agency on multichip modules (MCMs). MCMs are large semiconductor wafers with numerous microprocessors, or chips, mounted on them. Superconducting interconnects between these chips could be over 10 times smaller than conventional metal interconnects. This would allow computer chips to be stacked closely together, while avoiding cross talk between chips.

A Primer in Superconductivity

When cooled to a certain critical temperature–usually very close to absolute zero–superconductors abruptly become 100 percent efficient at conducting electricity. Previously, practical possibilities for superconducting materials seemed remote because scientists had to use liquid helium, which is expensive and cumbersome to work with, to reach the critical temperature of 4 to 24 Kelvin, or -452° to -416°F.

Recent discoveries in high-temperature superconductors have allowed researchers to use liquid nitrogen, which is a much cheaper and more efficient cryogen. Still, HTS materials are brittle and are not easily made into the wire needed for most applications. To circumvent this problem, scientists have begun to apply the material in thin films on a substrate.

One hurdle in manufacturing an HTS thin film is finding a substrate compatible with the superconducting material. The substrate should be a good electrical insulator and align closely with the lattice of the crystallized HTS material.

To meet these requirements, STI has developed a thallium barium calcium copper oxide (TBCCO) superconducting thin film grown on a lanthanum-aluminate ($LaAlO_3$) substrate. TBCCO is advantageous because it acts as a superconductor up to the relatively high temperature of 100 Kelvin, or -279°F. $LaAlO_3$, in turn, has a high dielectric constant (about 24) and a low loss tangent (3×10^{-5}), both of which indicate the material's ability to insulate electrically. The substrate's good insulating qualities make the superconducting system highly efficient and allow it to carry the maximum current.

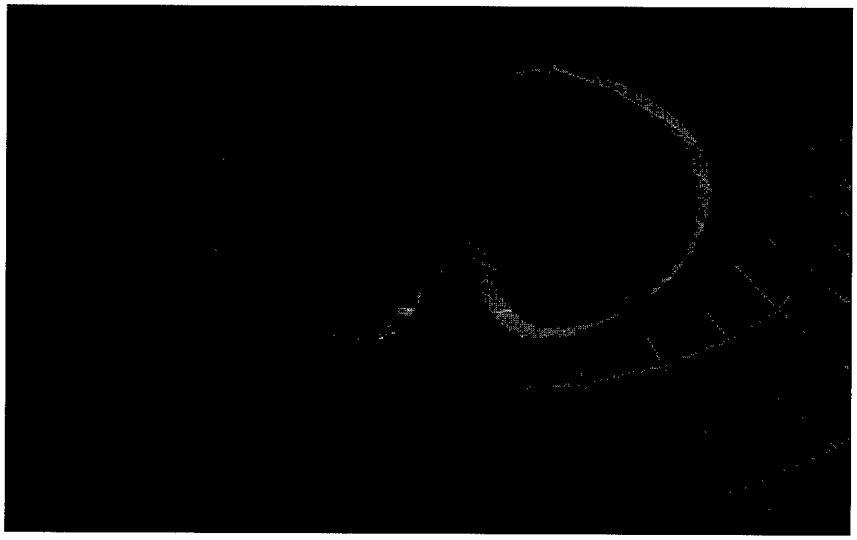
Partners w/Industry

Clamshell Embellishes Communication Systems with Better Performance

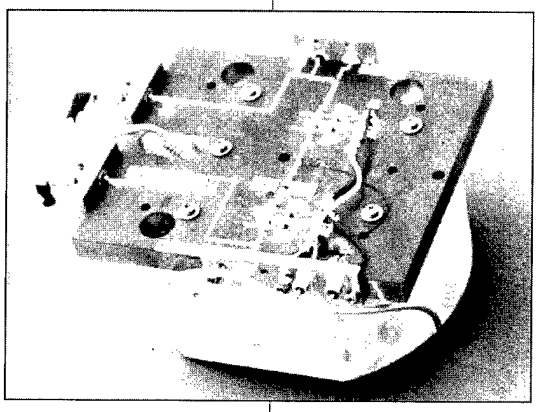
Usually, if the cryocooler in a superconducting system fails, the system fails too. A clamshell design used in radar receivers, however, yields better performance no matter the temperature. This design is the result of collaborative research—supported by BMDO for its application to satellite communications—between Xsirius Superconductivity, Inc. (Camarillo, CA) and Los Alamos National Laboratory (LANL).

In this project, Xsirius Superconductivity and LANL developed a high-temperature superconducting (HTS) thin-film cavity that can improve the performance of many electronic components, such as communications systems, microwave radar receivers, Doppler weather radar, and microwave test equipment. The technology can also enhance satellite communications, such as those used to transmit high-definition television signals.

An exclusive licensing agreement for the thallium HTS thin-film cavity has been established between LANL and Xsirius Superconductivity, which plans to pursue commercial markets after conducting further R&D to lower costs and fully refine the device. Also, LANL has submitted a patent on a low-phase-noise-clamshell microwave cavity, which has a clamshell shape but uses conventional copper materials.



Above *A graph showing the clamshell design of a microwave cavity. This design is the result of BMDO-funded collaborative research between Xsirius Superconductivity, Inc. and Los Alamos National Laboratory.*



Right *This low-phase-noise microwave cavity can improve the performance of communications systems, microwave radar receivers, Doppler weather radar, and microwave test equipment.*

The Secret of the Clamshell

When used as an oscillator for radar detection, the clamshell shape provides additional stability, reducing sensitivity to external vibration. Even without its super-conducting thin film, this device has significantly less phase noise and longer ranges than conventional dielectric resonator oscillators (DROs). Therefore, it is not expected to experience down time if cryogenic cooling is lost.

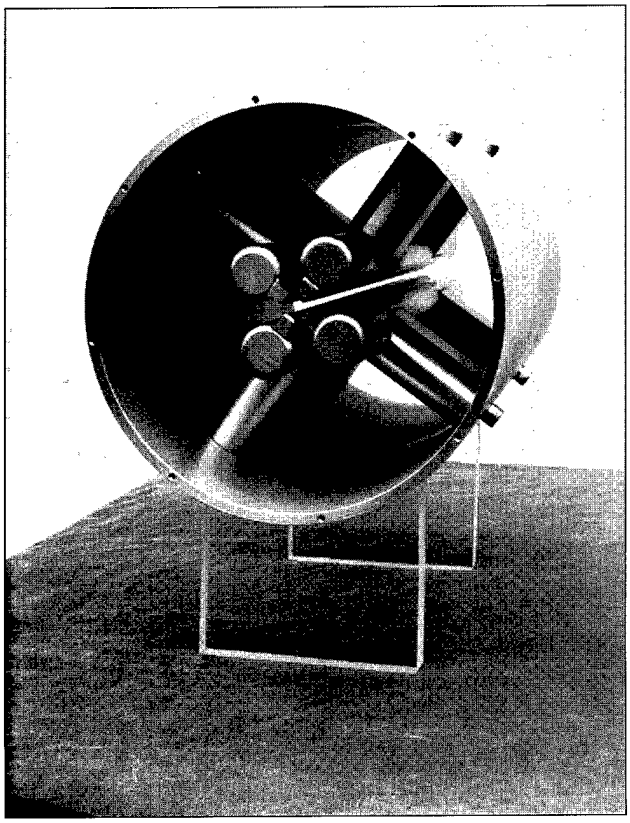
The quality factor (or efficiency) of the HTS cavity is 100 times better than the DRO. A non-superconducting version of this design increases the range of radar detection by 19 to 33 percent without increasing power or requiring cryogenic support. Phase noise of the device is reduced nearly 1,000 times at room temperature and nearly 10,000 times at cryogenic temperatures.

Premier Accelerator Firm in CRADA with Argonne National Laboratory

AccSys Technology, Inc. (Pleasanton, CA) has entered a Cooperative Research and Development Agreement (CRADA) with Argonne National Laboratory (ANL) to develop a smaller and more powerful radio frequency quadrupole linear accelerator (RFQ linac) using superconducting technology.

AccSys, the winner of a 1988 SDIO (BMDO) Technology Spinoff Award, was started by former Los Alamos National Laboratory employees to commercialize RFQ linac technology developed for the BMD Neutral Particle Beam program. Today, AccSys has over 40 employees and sales of approximately $6 million. Furthermore, *Inc.* magazine included AccSys on its "Inc. 500" list in 1991 and 1992 as one of the 500 fastest growing small businesses in the country.

AccSys currently markets a non-superconducting RFQ linac for use in cancer therapy, nondestructive testing, accelerated decay of radioactive waste (also known as transmutation of nuclear waste), subatomic particle research, and mineral assays (for more information on these applications, see the 1992 and 1991 *Technology Applications Reports*). Applying superconducting technology to the RFQ linac could result in smaller devices with increased particle energies and efficiency. This may help commercialize RFQ linac technology in areas where smaller, higher-voltage devices are needed.

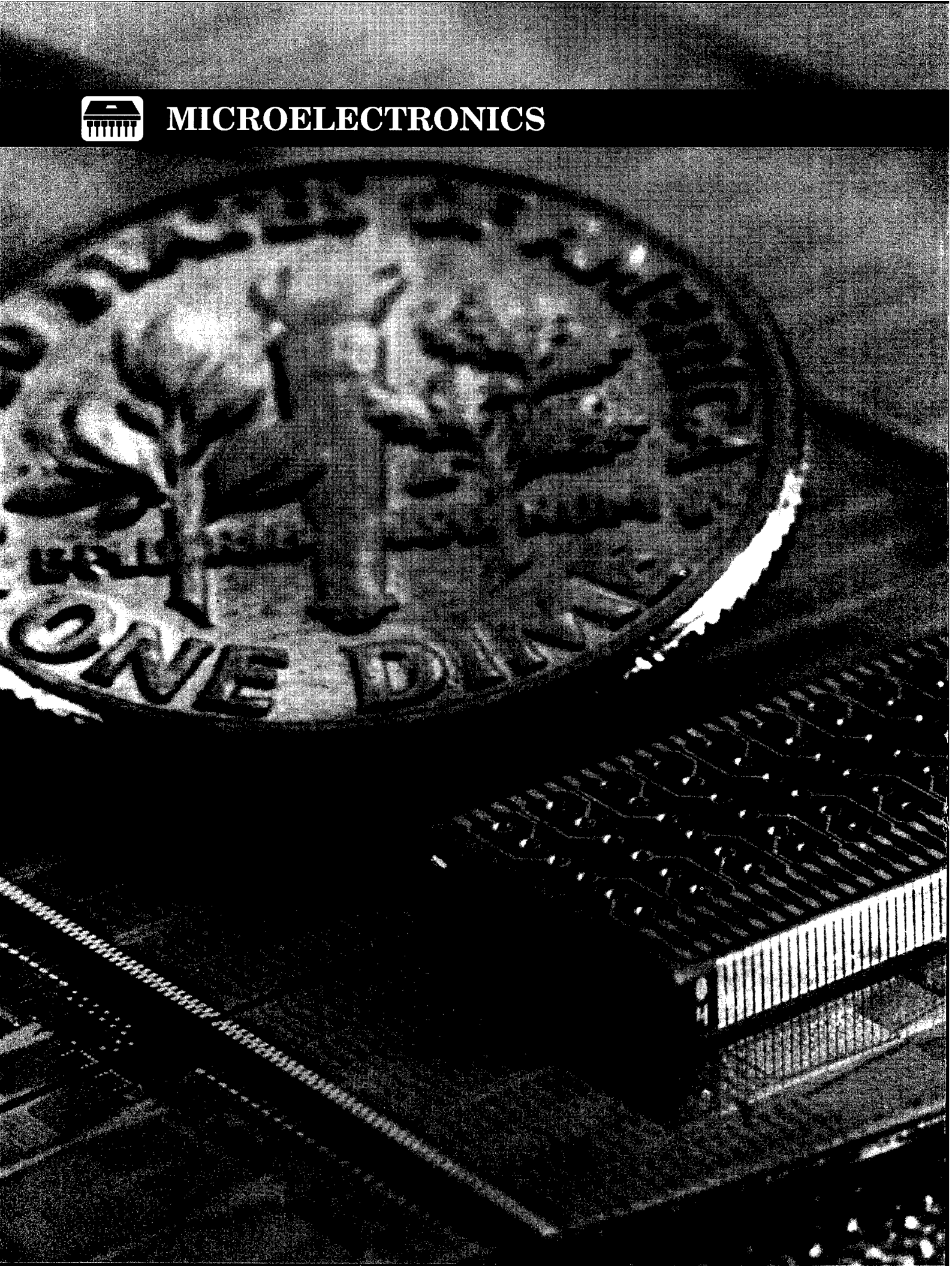


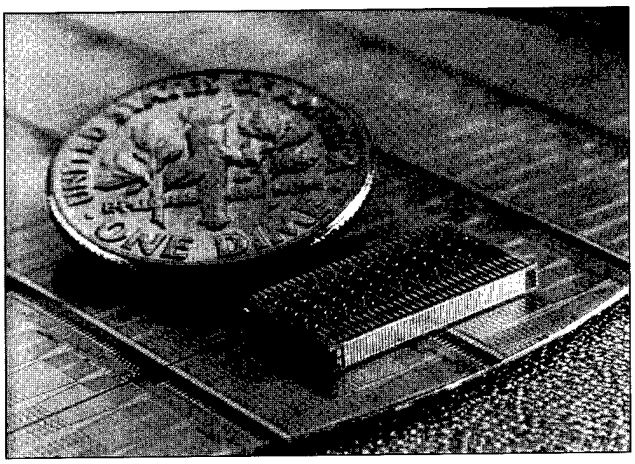
Above *The inside of AccSys Technology, Inc.'s RFQ linac. By producing electromagnetic fields with superconducting components, AccSys could dramatically cut the size of the accelerator, thereby making it more attractive for commercial and military applications requiring smaller, higher-voltage accelerators.*

The Niobium Superconducting RFQ

An RFQ linac employs radio frequency (RF) electromagnetic fields to both accelerate and control the direction of charged particles along the axis of a cylindrical tube. Superconducting components produce stronger RF fields in a smaller system than conventional copper components, possibly 10 times stronger according to preliminary studies. Superconducting components also reduce the RF power requirements. As a result, the superconducting RFQ could produce powerful beams of any element, from the lightest (hydrogen) to one of the heaviest (uranium), for a variety of applications in research and medicine.

The current prototype model under construction is a half-meter long and designed to have a high RF field under continuous operation. Production units, however, could be several meters long. (The length of the prototype was limited so that existing facilities at ANL can eventually be used for testing the accelerator beam.) Cooled with liquid helium at 4.6 Kelvin, the prototype is made of niobium (a superconducting material). The team expects that less than 10 watts of cooling will be required to maintain the device at its operating temperature.


MICROELECTRONICS



Irvine Sensors Corporation - Page 19

To the scientist, it is the difference between slow number crunching on a supercomputer of the 1970s and complex simulations on a desktop workstation of today. To the accountant, it is the difference between an adding machine and a spreadsheet. To the writer, it is the difference between a typewriter and desktop publishing.

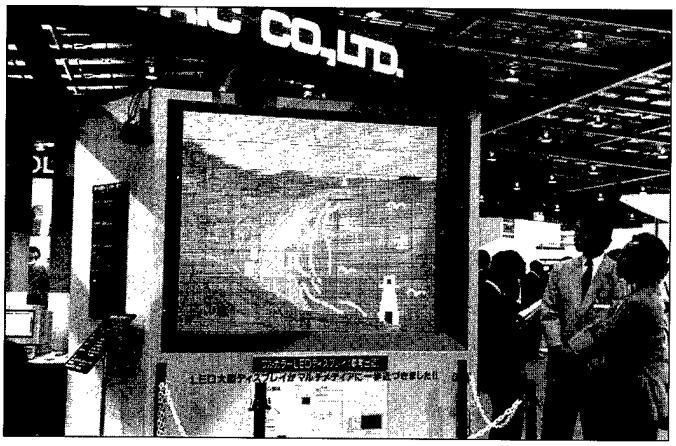
Smaller, faster, and more powerful microelectronic devices have changed the world, and the more we learn what they can do, the more we demand from them. Ballistic missile defense is no exception. BMD requires lighter, faster, and more accurate interceptors; sensors that acquire more accurate data; and command and control centers that obtain more timely information and respond to crises more effectively. As in the rest of the world, microelectronics dictate much of what BMD can and cannot do—and BMDO-sponsored research is shortening the list of "cannots" for itself and American businesses.

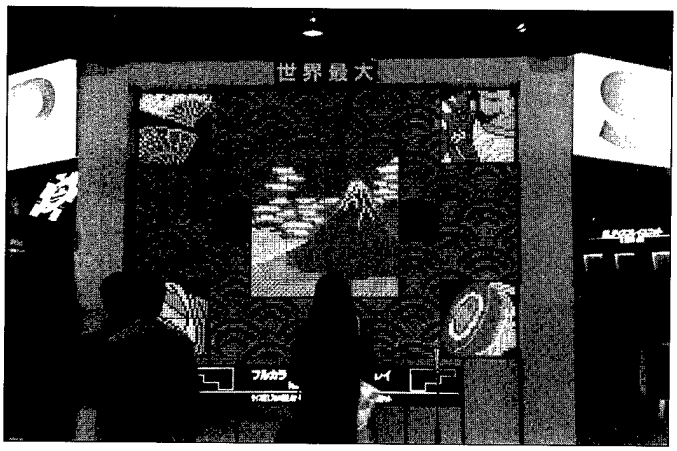
Blue Light Emitting Diodes Complete the Color Spectrum

In the world of electronics, you can make any color by mixing a combination of red, green, and blue. Until recently, only red and green light emitting diodes (LEDs) could be made. The recent development of a silicon carbide (SiC) LED with the ability to emit blue light, though, has changed the world of color displays forever.

This LED—developed and manufactured by Cree Research, Inc. (Durham, NC)—is now an important component in consumer and industrial products designed to display, recognize, or replicate colors. Products incorporating Cree's blue LED include large-scale flat-panel displays, color recognition sensors, color slide and film scanners, and digital color photographic printers. In addition, blue LEDs can be used in blood-gas analyzers to monitor blood-gas levels.

This LED is the first silicon carbide-based device to be commercialized. Other beneficial properties of SiC semiconductors include high-temperature operation, long-term storage of electrical charge (see next page), and generation of high-power microwave signals. This wide range of beneficial properties prompted BMDO SBIR funding of the technology for missile defense applications. Cree currently distributes its blue LED products domestically and in Europe, Korea, and Taiwan. The company also recently completed an initial public offering of common stock, securing $12 million in investment capital.



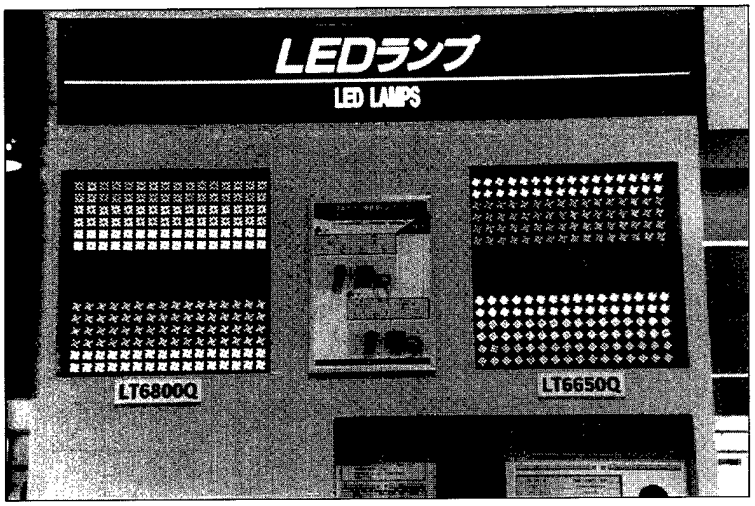


Silicon Carbide Chips Never Forget

Today, when you turn off your computer, you must save everything on a magnetic or optical disk or you will lose that information. This process is not only inconvenient, especially with laptop computers, but also increases the power burden on a computer. A new charge storage cell, though, may end these shortcomings in computers of the future. Now under development at Cree Research and Purdue University (West Lafayette, IN), this cell could store information even when computer power has been interrupted, such as during a storm or blackout. The cell should also provide fast read/write speeds and the potential for very large scale integration.

This nonvolatile random access memory (NVRAM) device, initially funded by the BMDO SBIR program, is made of silicon carbide (SiC) and could have storage times long enough (possibly years) to replace rotating magnetic media in portable and mainframe computer systems. Other benefits of the SiC memory include improved reliability and reduced size, weight, power consumption, and cost.

By reducing power and extending memory, SiC cells will improve computer systems used everywhere, from satellites to notebook-sized personal computers. As a result, Cree has secured three major contracts to develop this technology further: a $2.4 million Advanced Research Projects Agency contract, a $2 million National Institute of Standards and Technology Advanced Technology Program grant, and a three-year, $4.2 million BMDO IS&T project.

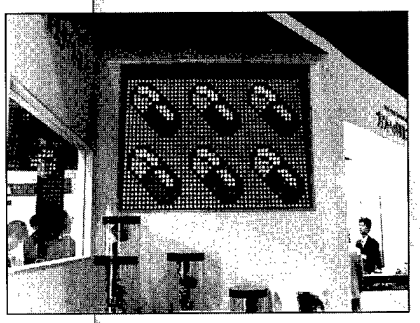


Above, Right and Previous Page *Cree Research, Inc. recently demonstrated its blue light emitting diodes in full-color displays at the 1992 Japan Electronics Show, held in Osaka, Japan. These blue LEDs resulted from BMDO-sponsored research in silicon carbide. Cree is also using silicon carbide to develop a non-volatile computer memory storage chip.*

Why Silicon Carbide Never Forgets

In today's computers, read/write memory is implemented primarily with silicon dynamic random access memory (DRAM) chips. DRAM chips store data through the presence or absence of charge on a metal-oxide-silicon capacitor. This capacitor, though, borders a silicon junction that produces thermally generated leakage currents. These leakage currents gradually discharge the capacitor, which means the computer must continually read and rewrite each cell to retain data, a process known as refreshing. Refreshing consumes considerable power—in military applications up to 80 percent of the total power required to operate the computer.

Cree's new cell is fabricated from SiC, which has an energy bandgap 2.5 times larger than that of silicon. As a result, thermally generated leakage currents are thousands of times smaller, allowing memory cells made in SiC to retain data for extended periods without refreshing. This reduces the read/write memory's power consumption to near zero. SiC semiconductors can also be used for a variety of wide-bandgap electronic devices and high-temperature electronic chips.



Chip Stacking: A Billion Dollar Lesson in Geometry

When electronic engineers could not fit any more devices on a single silicon chip, they began to mount chips side-by-side on the same board. With a flat board, though, chips on opposite corners do not easily connect to each other. A more efficient packaging technique would be to stack chips on top of each other. This 3-D architecture would cut the length of chip interconnections, thereby producing smaller, faster multichip modules (MCMs).

Irvine Sensors Corporation, or ISC (Costa Mesa, CA), has developed just such a 3-D chip stacking technology, which the BMDO SBIR program funded for surveillance sensors, neural network processor chips, and stacked memory chips.

ISC has formed two joint ventures with International Business Machines (IBM) to develop stacked memory devices. In the first venture, formed in June 1992, the two companies will develop advanced random access memory (RAM) devices using cubing technology. ISC also formed a second agreement with IBM in December 1992 to develop Short Stack™ memory chips.

Short Stack™ memories may be the most cost-effective way to develop the next generation of static RAM and dynamic RAM chips, since it presently costs about $1 billion to build the facilities that can achieve low defect densities for these chips. Short Stacks™ can achieve the same results for tens of millions of dollars.

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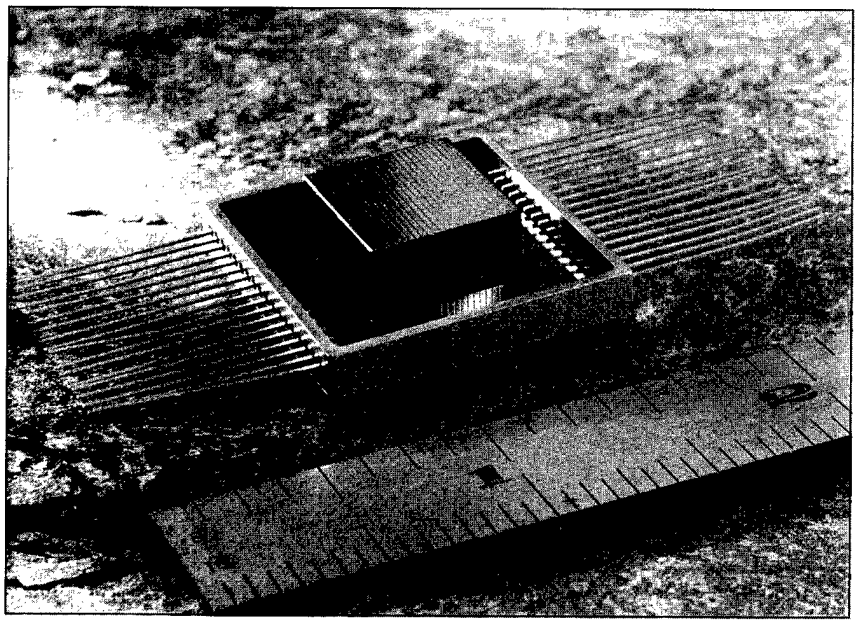


Above *Irvine Sensors Corporation's Memory Cube. This 3-D stack, or cube, maximizes the use of design space far more efficiently than typical planar packaging techniques. Irvine Sensors has stacked as many as 70 integrated circuits in this cube, resulting in a typical temperature rise per watt of dissipation of 1°C.*

Producing and Using 3-D Multichip Modules

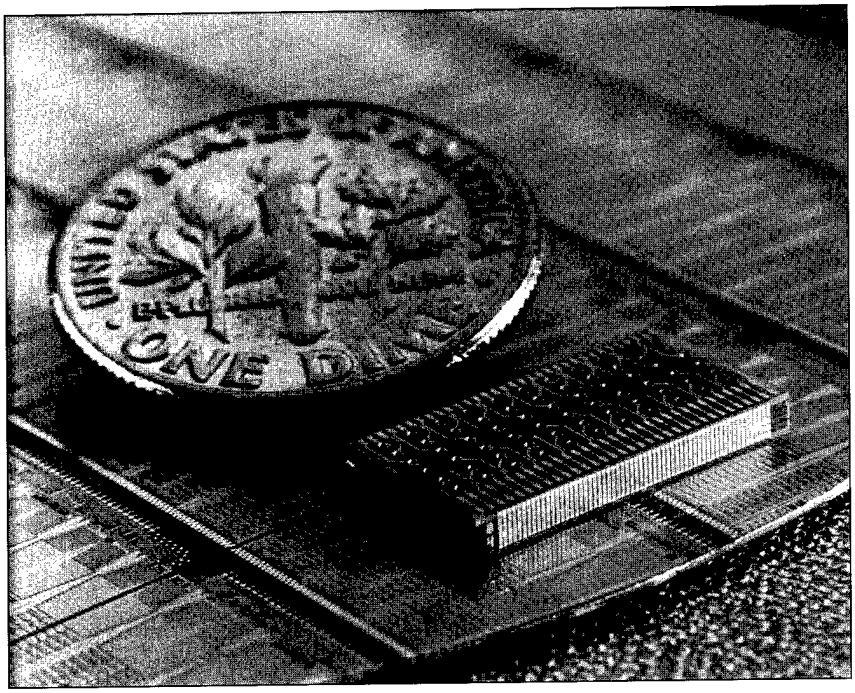
To produce a 3-D MCM, wafers are polished to less than 200 microns in thickness, patterned, and diced to form a separate integrated circuit. After surface metallization the chips are stacked together, aligned, and bonded with a thermally compatible epoxy. Raised metallic connections on the surface of each chip provide electrical contact between adjacent chip elements. The through-thickness electrical connections reduce circuit path lengths, thereby increasing the operating speed of the module. The shorter current paths also reduce overall power consumption of the module.

Irvine has developed 3-D MCMs for the following applications:

■ ***Smart Sensors.***
BMDO supported ISC's developments in smart sensors for space-based infrared imagers. To make these smart sensors, ISC stacks a planar detector array, amplifier circuits, and signal processor electronics in the same electronic package. This miniaturized package improves the sensor's signal-to-noise performance, speed, and power consumption. In the sensor, the digital detector array produces many pixels of information that require identical control and signal processing functions. Also, the more devices per chip, the more important it is to decrease the number of chip-to-chip interconnects and the length of those interconnects. Space-based infrared imagers are thereby well-suited to a parallel process architecture such as Irvine Sensor's chip stacking concepts. ➟

As a result, chip stacking should enter the semiconductor business mainstream during this decade. ISC and IBM anticipate producing initial quantities of these devices sometine this year.

ISC has collaborated extensively with NASA's Jet Propulsion Laboratory, which has pioneered developments of neural net processor hardware, to build neural nets with stacked-chip processors. ISC is also subcontracting for Grumman Aerospace to develop an integrated focal-plane array surveillance sensor. Grumman has designed the infrared sensor array itself, and Irvine will stack the signal processor chips and integrate them with Grumman's detector chip.



Above *Irvine Sensors Corporation's Memory Short Stack™. This device, which contains up to ten memory chips, fits in the space currently occupied by a single computer chip. Irvine Sensors has licensed this technology to IBM Corporation and is working with IBM to incorporate Memory Short Stacks™ into commercial electronics products and electronics used in NASA missions.*

■ ***Neural Networks.***
Under NASA and BMDO SBIR programs, ISC is also working on a 3-D neural network microprocessor. Artificial neural networks are functionally the same as brain processes; they enable pattern recognition and learning behaviors that are difficult for conventional computers to handle. Thus, a neural net processor involves large numbers of data and processing nodes that continuously interact with each other. The ISC chip stacking techniques can achieve the high interconnect densities necessary to construct an efficient neural network. When fully realized, the stacked-chip processors could approach or exceed the speed and connectivity of the human brain in an extremely compact package.

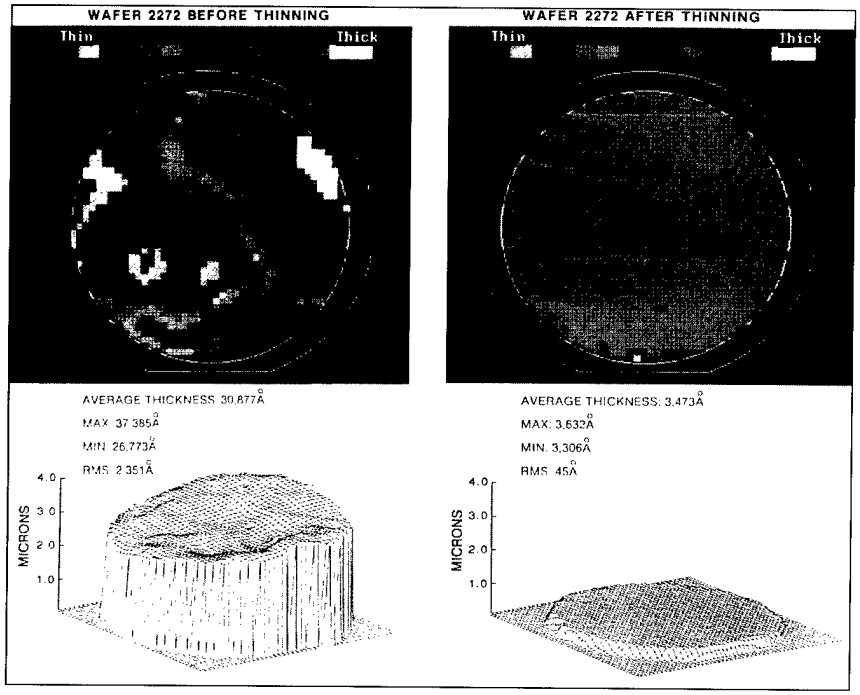
■ ***Memory Chips.***
Using its expertise in 3-D chip packaging, Irvine Sensors has developed advanced RAM devices made from 3-D chip packages of up to 100 silicon semiconductor wafers called dice. Irvine calls this approach "cubing"; it is closely related to the chip stacking processes used in the applications mentioned previously. Irvine has also developed Short Stack™ RAM devices that consist of about 10 short RAM chips vertically stacked on each other and edge-bonded to a silicon substrate. The resulting package has the same size as a current single-chip RAM memory module, but with 4 to 10 times the memory capacity and much faster access times.

Optics Polishing Produces Faster Computer Chips

Both precision optics and semiconductor manufacturing require extremely fine-scale polishing, since a cut hundreds of times thinner than a hair could ruin either device. As a result, Hughes Danbury Optical Systems, Inc., or HDOS (Danbury, CT), has taken a radical new method of polishing precision optics and used it to make bonded silicon-on-insulator (SOI) wafers. These SOI wafers, sold under the trade name AcuThin™, approach the speed of devices made from more expensive gallium arsenide wafers.

The Perkin-Elmer Corporation developed the polishing technology, known as plasma-assisted chemical etching or PACE (see sidebar), for the BMDO Rapid Optics Fabrication Technology program. In addition to semiconductors, PACE can fabricate aspheric optical surfaces, which provide better image resolution and wider field-of-view than standard spherical-shaped mirrors, but are more difficult to make. PACE can also produce synchrotron and telescope mirrors.

HDOS received a license for the PACE process as part of Hughes Aircraft's acquisition of Perkin-Elmer's Electro Optical Technology Division. In addition, members of the PACE process development team are now HDOS employees and HDOS is further developing the PACE process. This group has developed, published, and experimentally verified a theory explaining how the PACE process smoothes surfaces. With this theoretical basis, researchers can model the PACE process and its results on real surfaces.



Above *These two pictures compare the thickness and uniformity of a silicon wafer before (far left) and after it has been polished with Hughes Danbury Optical Systems' PACE process. With the help of this process, which BMDO funded to polish precision optics, HDOS's AcuThin™ wafers can approach the speed of more expensive gallium arsenide wafers.*

How PACE Works

In PACE, hot plasma (ionized gas) reacts with the surface material to generate a volatile product that chemically removes a highly predictable and controllable amount of material. The plasma reaction fine-polishes and finishes the mirrored surface while removing material.

Unlike mechanical processes, PACE can figure (coarse and fine shapes) and polish optical surfaces; further, PACE does so without damaging the subsurface structure. PACE has successfully removed quartz at rates greater than 1 cubic millimeter per minute without fracturing the subsurface and crystalline silicon at 10 cubic millimeters per minute. It can smooth a rough-ground silicon surface with root mean square (RMS) roughness of 300 microns, and reduce it to an RMS of 300 ångströms (10,000 times smoother). With each cut, PACE can get within 95 to 99 percent of the desired polish before one must remeasure. In normal mechanical processes, opticians must remeasure after reaching about 50 percent of the desired polish. Overall, PACE is 10 times faster than conventional processes.

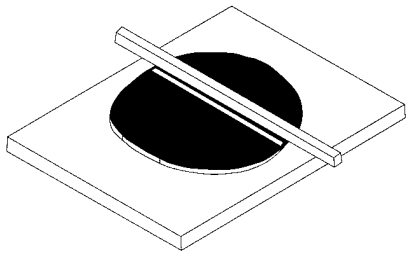
Better Chipmaking Yields Better Flat-Panel Displays

Kopin Corporation is developing active matrix liquid crystal displays (AMLCDs) that cost less and perform better than conventional AMLCDs, a flat-panel display technology invented in the United States but now manufactured almost entirely abroad. Kopin plans to introduce AMLCD products, marketed under the trade name Smart Slide™, sometime this year.

Kopin produces AMLCDs using wafer engineering technology developed with the help of early BMDO SBIR contracts (see sidebar). Today, Kopin is using similar wafer-engineered materials for high-temperature microsensors used in industrial and aerospace applications. These sensors, also to be offered commercially sometime this year, have greater precision and function at much higher temperatures than typical polycrystalline silicon sensors. The company's wafer technology also can produce radiation-hardened static random access memory circuits.

To develop AMLCDs, Kopin has won two flat-panel display contracts: one with the Advanced Research Projects Agency and one with the Department of Commerce. In the Department of Commerce project, Kopin will develop high-resolution, price-competitive AMLCDs in conjunction with the Microelectronics and Computer Technology Corporation, a research consortium of computer companies. Kopin became a publicly owned company on April 15, 1992, and raised $15 million in its initial public offering. The company raised an additional $25 million in a second offering in March 1993.

Above *Isolated silicon epitaxy equipment. This equipment is used to produce silicon-on-insulator wafers for active matrix liquid crystal displays, high-temperature microsensors, and radiation-hardened static random access memory circuits.*



Above *This drawing depicts the isolated silicon epitaxy process, which produces a thin single crystalline silicon film on a thermally oxidized silicon substrate.*

Wafer Engineering Improves Chipmaking

Wafer engineering combines different semiconductor materials to improve chip performance and extend the chip's range of use. During its BMDO SBIR projects, Kopin developed high-temperature silicon-on-insulator (SOI) microsensor structures and GaAs-on-SOI wafers for strategic radiation-hardened electronics.

Much of Kopin's wafer engineering technology relies on Isolated Silicon Epitaxy (ISE™), which produces a thin single crystalline silicon film on a thermally oxidized silicon substrate. The silicon film is created by vapor deposition and converted to a single-crystal layer using the company's proprietary scanning recrystallization technique. This film raises the circuit radiation resistance, as well as the voltage and temperature thresholds. Also, ISE™ wafers have 30 percent higher circuit densities and operate twice as fast as components fabricated in bulk silicon.

Kopin's family of microsensors combines ISE™ wafer technology with emerging micromachining technologies. ISE™ wafer technology also allows Kopin to build AMLCDs using single crystalline silicon. With single crystalline silicon, display circuits can be produced using standard integrated circuit manufacturing techniques and transferred to glass after wafer processing. In contrast, conventional AMLCDs are made using amorphous or polycrystalline silicon. Therefore, manufacturers must place these AMLCDs on glass screens using costly silicon-on-glass fabrication techniques.

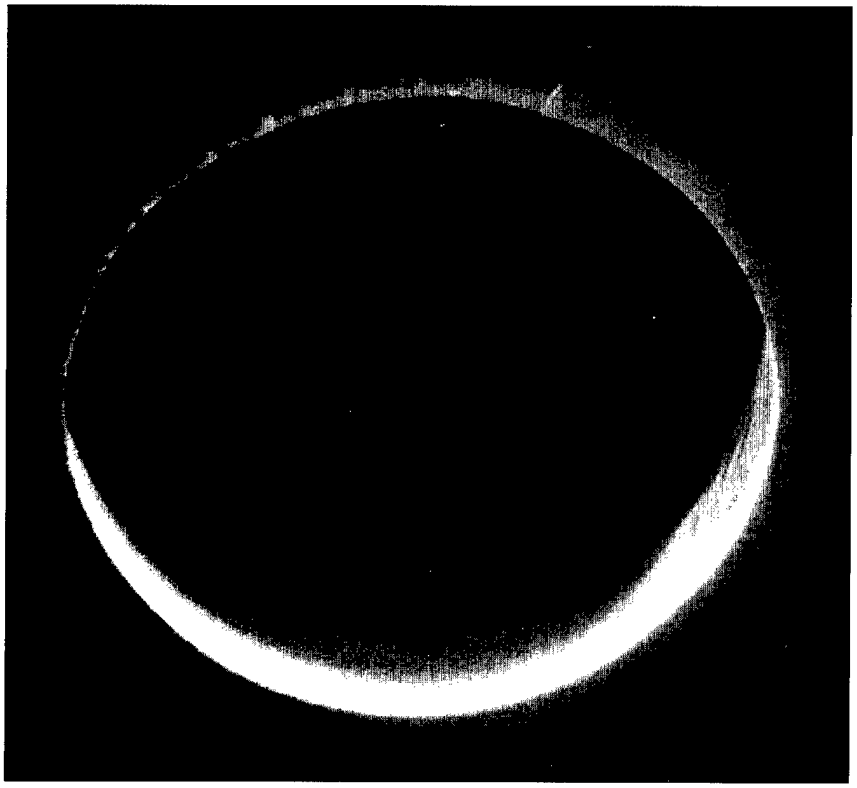
Technology to Watch

Insulating Material Promises Packaging Breakthrough

Maxdem, Inc. (San Dimas, CA) has developed a way to make polymers that could allow electronics to run 20 percent faster. What's more, Maxdem's polymers—called polyquinolines—cost less than competing materials such as polyimides.

Polyquinolines, which Maxdem developed in a BMDO SBIR contract, also resist heat and moisture, which means they could serve as a fiber sizing and matrix resin in high-performance composites. They also can be used as thermal control coatings and wire coatings in harsh environments.

Maxdem holds exclusive rights to polyquinoline preparation and composition methods, with other patents pending. The company has begun test marketing limited amounts of one polyquinoline under the trade name PQ-100™ and hopes to develop a full product line soon. Maxdem believes polyquinolines could someday meet 10 percent of the multimillion-dollar U.S. demand for high-temperature electronic substrates and is currently seeking partnerships that will help the company to achieve this goal.



Above *This image, taken with a scanning electron microscope, shows a hole drilled in a PQ-100™ film using a 248 nanometer laser. Because Maxdem, Inc.'s films are excellent electrical insulators, they allow electronics to run 20 percent faster than possible with other electronic substrates. The films are also more stable than other substrates, withstanding temperatures up to 650°C and absorbing little moisture.*

Physical Properties Yield Packaging Benefits

Polyquinolines, with an ultra-low dielectric constant of 2.6, are electrical insulators that protect against interference between integrated circuits on multichip modules. With less interference, signal processor clocks can reach extremely high speeds, from 8 to 12 gigahertz. Lower dielectric constants also allow thinner, lighter packages; polyquinolines have film densities of 1.35 to 1.45 grams per cubic centimeter.

Furthermore, because integrated circuits generate so much heat, all materials used in electronics packaging must be able to withstand high temperatures. Polyquinolines do not begin to decompose in air until 500°C and can withstand temperatures up to 650°C. Also, when exposed to radiation and moisture, competing materials such as polyimides tend to perform poorly. In contrast, polyquinolines absorb little moisture—0.15 percent uptake in 75 percent relative humidity (compared to 1 percent for polyimides). Finally, unlike other high-temperature polymers, polyquinolines are soluble in common organic solvents, which allows easier processing.

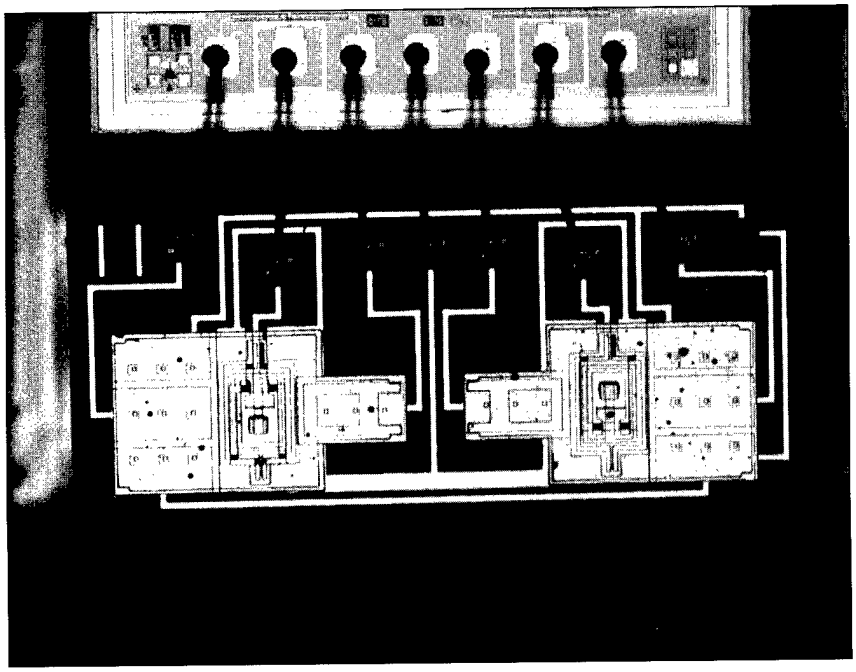
Accelerometer Guides Small Business to Commercial Success

Since 1990, Silicon Designs, Inc. (Issaquah, WA) has been selling an accelerometer that the company developed under BMDO SBIR contracts. Because of the accelerometer's low production cost, Silicon Designs also has licensed the technology to a U.S. Fortune 500 company to build accelerometers for automobile applications, such as air bag deployment modules and active suspensions. This company believes it could produce modules with a U.S. market value of $1 billion during the life of the product.

Silicon Designs is also using the sensors to build a family of low-cost contact fuses for tactical missiles, which they believe will cost half as much as current designs. The company has already built and successfully tested prototype units on an AMRAAM missile at the Naval Air Warfare Center at China Lake. Silicon Designs will begin developing production units for this application sometime this year. With additional improvements, the technology can be used to build ultra-fast contact fuses for theater missile defense. Military versions of the accelerometer have also been used in new safe-and-arm devices for the Javelin and Hellfire missiles, scheduled to begin low-rate production later in 1993.

Due to its small size, low cost, low power consumption, and ability to operate over a wide temperature range, the accelerometer has great potential. Other possible uses include:

- Automobile instrumentation
- Rate damping for autopilots
- Down-hole oil and gas drilling instrumentation
- Localized vibration measurements
- Tilt sensors.



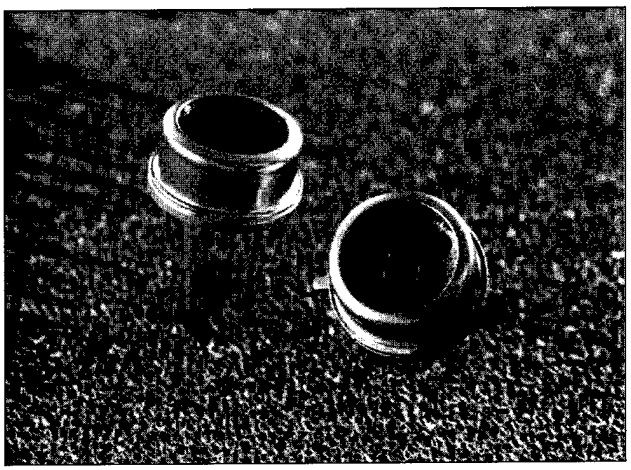
Above *Silicon Designs, Inc.'s accelerometer. A U.S. Fortune 500 company that has licensed this accelerometer believes it could produce air bag modules with a U.S. market value of over $1 billion during the life of the product.*

Accelerometer Comes in Small, Radiation-Proof Package

To navigate and guide BMD kinetic energy vehicles, Silicon Designs' accelerometer had to be small, consume little power, and operate over a wide temperature range and after long exposure to space radiation. The accelerometers developed in this project weigh less than 1.0 gram and occupy a volume of about 0.2 cubic centimeters, smaller than your fingernail. Tests show that the accelerometers can withstand up to 0.5 megarads of radiation without affecting their accuracy.

This accelerometer consists of two major components: a micro-machined sense element and a radiation-hard integrated circuit. Sense elements, which detect acceleration, are fabricated on the surface of a wafer using integrated circuit methods combined with selective electroforming. Radiation-hard integrated circuits, in turn, measure and digitize the acceleration detected by the sense element. They are assembled in small 20-pin leadless chip carriers. During the BMD project, Silicon Designs tested the accelerometers for radiation hardness at the Boeing Radiation Effects Laboratory.


OPTOELECTRONICS



APA Optics, Incorporated - Page 31

If today is the age of microelectronics, tomorrow may be the age of optoelectronics. Because optical signals travel faster than electronic signals, have smaller power losses, and do not interfere with each other, they can make computers, communications systems, and other devices faster and more efficient than their electronic counterparts.

With an eye toward improving the sensors, computers, and communications devices used in BMD systems, BMDO has been a leader in the optoelectronic revolution. Many American businesses have already benefited from this leadership, as BMDO-sponsored research has yielded a stream of new products, spinoff companies, and commercial collaborations. As the optoelectronic industry matures, the future will only get brighter.

Start-up Company

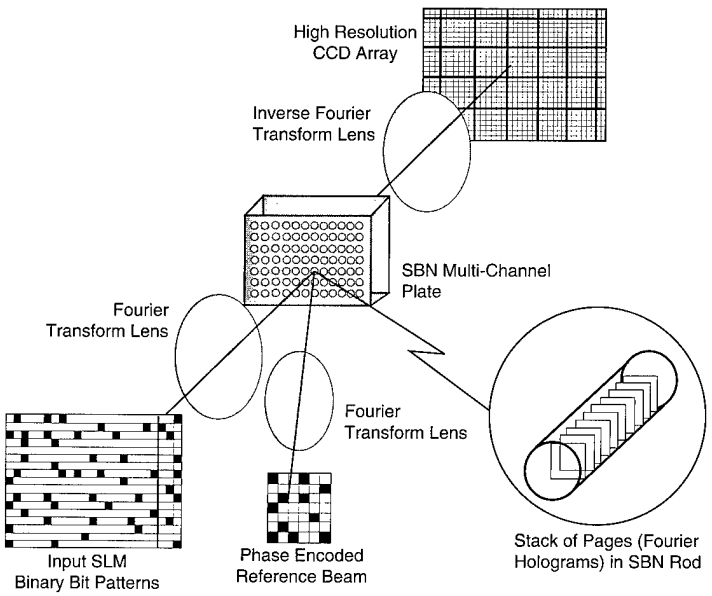
Optical Computing Start-Up Company to Build Optical Data Storage System

Because they take a long time to access, current mass data storage systems can bottleneck operations when processing large amounts of computer information. Thanks to a start-up company created by Stanford University researchers, storage technology may soon match the requirements of new, speedy processors. The start-up firm, Optitek, Inc. (Palo Alto, CA), specializes in computer technology based on SBN, an optical data storage material developed by the Stanford researchers during an BMDO IS&T contract (see sidebar).

Because SBN can store 10 to 100 times more data and allows computers to access data 1,000 to 10,000 times faster than present systems, it can be used for almost any application that requires massive amounts of information to be stored and quickly retrieved. Two systems currently employ SBN properties: holographic storage and reconfigurable interconnects.

By dramatically increasing the amount of data a computer can store and the speed with which it can retrieve data, holographic storage could replace disk drives and magnetic tapes in laptops, personal computers, and mainframes. It could also allow new multimedia applications, such as instant playback of movies, or store and quickly retrieve large warehouses of information. Furthermore, holographic storage could serve optical or electronic computers. Reconfigurable interconnects, in turn, can be used for a wide range of switching applications such as neural network pattern recognition.

As a first step toward commercializing SBN technology, Optitek is participating in a consortium with major industrial partners on a multimillion dollar R&D contract with the Advanced Research Projects Agency.



Above *A schematic of Optistore™, Optitek's holographic data storage engine. The plate in the middle of the diagram contains hundreds of SBN rods, which allow this system to store 10 to 100 times more data and provide access times thousands of times faster than present systems.*

What Exactly Is SBN?

SBN (short for $SR_{1-x}Ba_xNb_2O_6$) is a crystalline material with both ferroelectric and photorefractive properties. Because it is ferroelectric, applied electric fields can locally vary the material's optical properties; the photorefractive property, in turn, provides a basis for forming optical image patterns by shining light on the crystal. With these properties, image patterns can be stored inside the crystal in the form of holograms. SBN remains photorefractive below 75°C, which is the temperature at which SBN loses its ferroelectric properties. Thus, SBN can store data at room temperature for several months. At lower temperatures, data can be stored even longer.

During the first stages of R&D on SBN in the early 1970s, scientists had problems with data loss. Frequent data read-outs reduced data reliability; however, Stanford University found that data reliability could be substantially improved by exposing the SBN crystals to an electrical field. Stanford also eliminated cross-talk problems in SBN by using crystal fibers rather than large crystals. Crystal fibers are also less expensive to manufacture than large crystals.

These fibers form small SBN rods, which are about 1 mm in diameter and roughly 4 to 5 mm long. Each rod can store 30 to 50 holograms superimposed as stacks. For most applications, hundreds of these rods are packed tightly on a microchannel plate, allowing storage capacities of up to 10^{13} bits per cubic centimeter.

BMDO SBIR Spurs Breakthrough in Silicon Light Emission

Silicon, as the most abundant, least expensive, and most widely used electronic compound, has been the miracle material of the microelectronic age. But until recently, no one could make silicon efficiently emit light, a factor that limits its future role in the optoelectronic age.

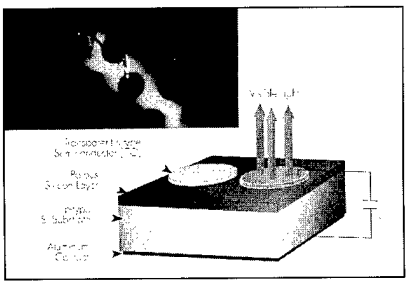
Because most silicon devices cannot emit light, researchers must bond other light-emitting compounds to silicon electronics to make integrated circuits that can transmit light signals, the holy grail of optoelectronics. The process of bonding unlike crystals such as silicon and gallium arsenide (GaAs), though, is difficult and expensive. If only silicon could efficiently emit light, highspeed electro-optical switching devices could make their way into everyday products.

Today, it looks like that wish may come true. Spire Corporation (Bedford, MA) researchers have developed a porous silicon device that emits light when stimulated by electricity. The device consists of a layer of porous silicon covered by a transparent film of indium tin oxide, which allows light emission through the top surface of the device.

Spire began to explore porous silicon's ability to emit light using laser stimulation, electricity, and a combination of the two during a BMDO SBIR contract. After demonstrating that visible light could be produced with applied voltage only, the company is continuing BMDO-sponsored research to learn more about the science behind the effect and to develop silicon light emitting diodes (LEDs). During this research, Spire researchers aim to build an LED array that can operate at 5 to 8 volts.

Several other groups are also trying to develop silicon-based devices, but Spire's device has one notable advantage: it works in the open air. In one test, it emitted light for as long as 85 hours. Other devices oxidize too quickly to work in open air, which means they must be encapsulated to emit light for longer than a few seconds. Spire's work also received a major boost when researchers at the U.S. Army Research Laboratory in Fort Monmouth, NJ confirmed its results.

Although commercialization of this technology is still a long way off, its long-term prospects are very good. Electro-optical switches made from porous silicon LEDs could become vital components of optical computers and communication devices, which operate faster and more efficiently than their electronic counterparts. Also, silicon LEDs could be used in flat-panel displays.



Above A diagram of Spire's porous silicon-based light emitting diode. The inset on the upper left-hand corner shows the internal structure of the porous silicon layers. Because this LED could be easily merged with silicon-based electronics, it could become, with further development, a vital component of optical computers, optical communications devices, and flat-panel displays.

Quantum Confinement or Oxy-Hydrides?

Now that researchers can make porous silicon emit light, scientists have begun to debate the possible reasons why. Some have attributed the effect to quantum confinement in the nanoscale pore structure, while others claim the presence of oxy-hydrides on the pore walls cause luminescence.

Spire's research strongly suggests that quantum confinement causes this effect; that is, pores at the interface between the two layers confine electrons to atomic dimensions. By doing so, the pores localize the electrons in quantum states. By applying 10 to 20 volts across the interface, researchers can excite electrons into higher energy states so that the porous silicon emits light in the red-orange region of the visible spectrum.

On the basis of three independent measurements, Spire's results indicate that observed electro-luminescence (EL) originates from minority (electron) carrier injection, the basic mechanism operating in GaAs-based LEDs or other homojunction devices. Furthermore, the finding indicates that EL should be possible with the same efficiency levels as the photoluminescence (PL) that was observed for porous silicon. No physical or fundamental problems have been observed that would otherwise limit the efficiency of emissions of these devices. Without any fundamental limits, Spire researchers believe high-quality materials and optimized processing will soon yield EL in porous silicon devices more efficient than ever thought possible.

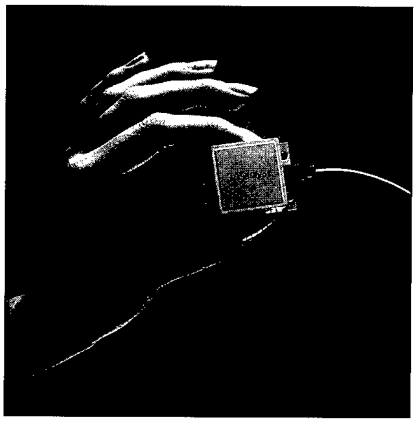
First Two Products on the Market for MICRACOR™

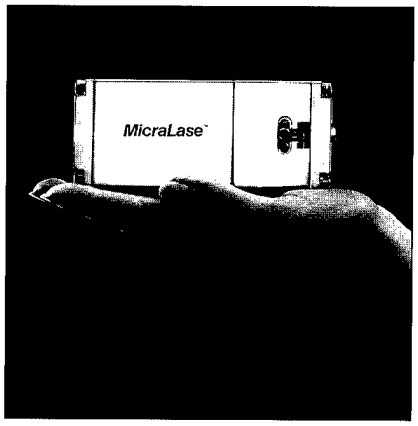
In 1988, researchers at the Massachusetts Institute of Technology's Lincoln Laboratory dreamed of market riches. They had just developed an impressive new technology called microchip lasers (see sidebar) for BMDO, and they knew these lasers could change the worlds of communications, medicine, and computers.

These researchers formed a new company called MICRACOR, Inc. (Acton, MA), built a 7,000-square-foot manufacturing facility, and recently introduced two products: MicraLase™—a tunable, external-cavity semiconductor diode laser—and MicraChip™—a miniature diode-pumped solid-state laser. MicraLase™ provides a high-quality, reliable, and low-cost replacement for dye and titanium-sapphire lasers for medical and scientific applications. MicraChip™, in turn, will be sold for communications, cable television, optical disk, display, and printer applications.Demand for these products recently allowed MICRACOR™ to expand to a new 12,000-square-foot manufacturing plant.

MICRACOR will also soon introduce a third product, MicrArray™—a two-dimensional laser display that combines high power with the reliability of solid-state lasers. Individual elements of the MicrArray™, as well as the power supplies that drive them, can be operated independently or in subgroups.

MICRACOR estimates that microchip lasers could eventually capture a large share of the current $1 billion-a-year laser market. A share of the current laser market, however, may understate MICRACOR's opportunity when considering the new markets microchip lasers may create. For example, the microchip laser's tunability allows it to send many optical signals simultaneously over a single fiber. Multiple signals could greatly increase the capacity of telephone optical switches, or the amount of data sent between computers. Microchip lasers also could create cost-effective medical applications in cancer therapy, dermatology, and eye and heart surgery.





Above *MICRACOR™ 's two microchip laser products: MicraChip™ and MicraLase™. Demand for these products has allowed MICRACOR™ to expand to a new 12,000-square-foot manufacturing plant.*

Advantages of Microchip Lasers

Microchip lasers offer the size, cost, and reliability advantages of diode lasers, with the beam quality of more expensive solid-state systems. They have a line width (a measure of how accurately lasers produce a desired single frequency output) of less than 7 kilohertz–over 1,000 times more accurate than the line widths of conventional diode lasers.

In other solid-state lasers, the mirror at one end of the cavity—where light reflects back and forth—must be slightly curved to help stabilize the beam. In contrast, beams in microchip lasers are stabilized by thermal waveguides created by heat generated in the chip. Thus, microchip lasers can use flat mirrors, which simplifies manufacturing.

Microchip lasers also can be easily tuned to different frequencies using a variety of techniques including piezoelectric transducers, electro-optic tuning, or pump diode current modulation. The microchip laser cavity is the thickness of the chip; with such a small cavity, a small change in length results in a relatively large frequency shift. Thus, a microchip laser with a center frequency of 3×10^{14} hertz can be tuned over a range of 100 gigahertz.

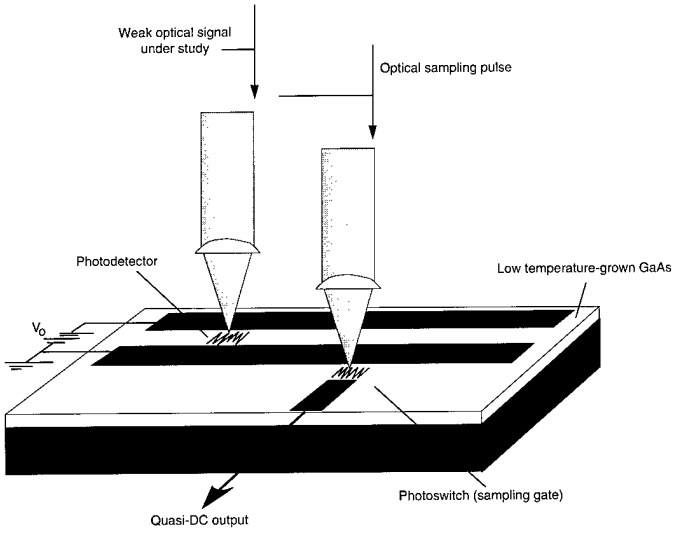
Electro-Optic Innovations the Basis of a New Company

In March 1992, a researcher from the Ultrafast Science Optical Laboratory at the University of Michigan formed Picotronix, Inc. (Ann Arbor, MI) to commercialize the fastest photodetector in the world. The University of Michigan developed this photodetector as the result of research on electro-optic modulators funded by the BMDO IS&T program. Picotronix is now setting up manufacturing of photodetector components, which should begin by early 1994.

Picotronix's photodetector technology could produce a wide range of products including a new class of ultrasensitive photodetectors for optical communications, optoelectronic-based testing instrumentation, and biomedical imaging. It also can be used for consumer-oriented, high-volume applications such as bar code reading from a distance or as a collision avoidance sensor for the automotive industry. Furthermore, probes using the photodetector technology can be used for electronic device testing.

In a BMDO SBIR contract, Picotronix is developing a sampling optical temporal analyzer (SOTA), a device that uses two photodetectors to detect and digitally analyze an optical signal in less than 2 picoseconds, or two-trillionths of a second (see sidebar). Picotronix recently received a $1.3 million contract from the U.S. Army Tank-Automotive Command to develop a SOTA-based laser radar sensor used for collision avoidance in Army systems. This sensor could be used in cars of the future to help drivers avoid crashes.

Picotronix also has received a NASA SBIR contract to conduct R&D on a noninvasive voltage probe for testing internal-node integrated circuits. This probe has a time resolution of 1 picosecond and a spatial resolution of 1 micron, or one-millionth of a meter.



Above *The Sampling Optical Temporal Analyzer or SOTA. Picotronix, Inc. recently received a $1.3 million contract from the U.S. Army Tank-Automotive Command to develop a SOTA-based laser radar sensor for collision avoidance in Army systems. This sensor could be used in cars of the future to help drivers avoid crashes.*

Photodetectors Grow From Optical Communications Research

The BMDO IS&T program funded research at the University of Michigan to develop high-speed electro-optic modulators that operate at bandwidths over 100 gigahertz. With bandwidths this broad, these devices can modulate a wide range of signals, making them excellent components for optical communications systems. Systems employing these devices would be 10 to 50 times faster than current communications systems. To complement the performance of the modulators, the University also developed an advanced demodulator or photodetector.

This photodetector gave birth to Picotronix. Picotronix has recently demonstrated a photoconductive-type, one-picosecond photodetector. This photodetector, which is as sensitive as a conventional photodiode, consists of a gallium arsenide semiconductor made through low-temperature molecular beam epitaxy (MBE). The photodetector has the versatility to function as a detector at low optical intensities and as a switch, or sampling gate, at high optical intensities. By integrating the detector and gate on one chip, Picotronix has developed the world's fastest, most compact, ultrasensitive picosecond optical waveform analyzer. This completely solid-state chip is called a sampling optical temporal analyzer (SOTA).

The output from the SOTA is an electrical signal that can be measured using conventional electronics. At least 100 times faster than existing compact sensor technology, its one-picowatt sensitivity compares well to a conventional photodiode.

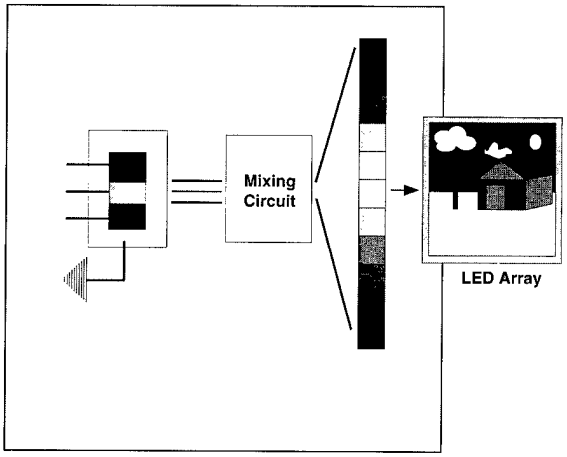
Blue Lasers to Increase Optical Data Storage Densities

North Carolina State University, or NCSU (Raleigh, NC), has established formal programs with the Eagle-Picher Research Laboratory (Miami, OK) to commercialize a method to make laser diodes and light emitting diodes (LEDs) that emit blue or green light (see sidebar). Using NCSU's technology, Eagle-Picher won a $1.75 million National Institute of Standards and Technology Advanced Technology Program award to develop blue/green laser technology. NCSU developed its production technology with funding from the BMDO IS&T program.

Blue/green laser diodes would have a dramatic impact on optical data storage, where the amount of data that can be stored depends on the wavelength of the light used to read and write data on a disk. Because blue/green laser diodes have shorter wavelengths than other read/write devices, they could greatly increase data storage densities in optical disks.

Blue laser diodes also round out the color spectrum for full-color displays, where inexpensive, high-brightness red and green light sources have been available for many years. In contrast, comparable blue light sources only became available very recently. The market for full-color devices, such as laser printers and flat-panel displays, may exceed $20 billion per year by the end of the decade.

Other potential applications include underwater communications (ocean water, as shown by its color, only transmits blue-green light), high resolution laser surgery, pollution monitoring systems, and optical spectroscopy. Furthermore, blue LEDs can be used for traffic signals, aircraft cockpit and automotive displays, and status indicators in consumer electronics and home appliances.



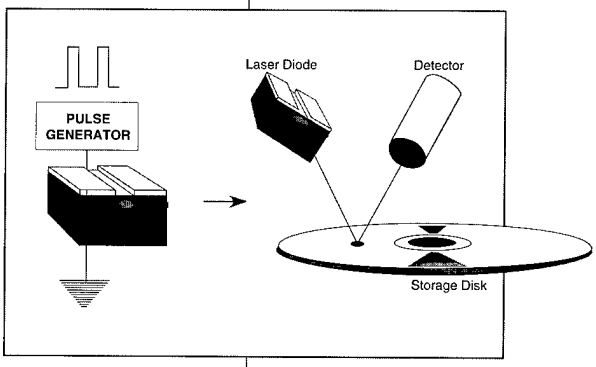
Above *A schematic of a full-color LED array. The market for full-color devices, such as laser printers and flat-panel displays, may exceed $20 billion per year by the end of the decade.*

Molecular Beam Epitaxy Produces New Blue/Green Lasers

Using molecular beam epitaxy, NCSU researchers have developed methods to produce blue/green laser diodes based on II-VI semiconductor heterostructures (compounds in the second row of the periodic table such as zinc, and compounds in the sixth row such as selenium). These diodes provide a light output with a wavelength of 471 to 520 nanometers, corresponding to blue/green in color.

The technology can produce continuous wave laser diodes at 77 Kelvin, or pulsed emission at up to 200 Kelvin. It can also produce blue and green light emitting diodes (LEDs) and ohmic contacts. The BMDO IS&T program supported research at NCSU in heterostructures and superlattices of mercury-based II-VI semiconductor devices, such as LEDs, lasers, and ultraviolet light detectors.

Below *A schematic of an optical data storage system. By employing North Carolina State University's short wavelength blue/green laser diode, this system would have much higher data storage densities than possible with lasers now used in these systems.*



Ultraviolet Sensors Go Commercial

Due to their many favorable properties, aluminum gallium nitride (AlGaN) and gallium nitride (GaN) semiconductors make excellent ultraviolet (UV) radiation emitters and receivers. Widespread application of the semiconductors, though, has been limited because they are difficult and expensive to manufacture. To overcome this barrier, APA Optics, Inc. (Blaine, MN) developed the first method to produce crystalline layers of GaN and AlGaN suitable for general use. APA developed the technique, along with doping and lithographic etching techniques, for the BMDO SBIR program to improve UV sensors used to detect ballistic missile plume signatures.

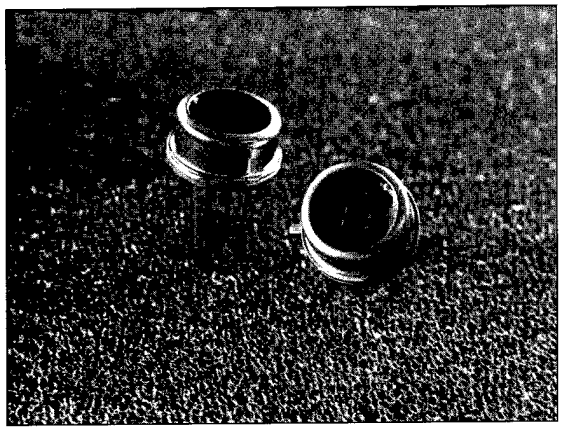
APA's UV sensors can monitor flames to improve efficiency and safety in steel furnaces and other industrial processes that employ combustion. So far, APA has produced and sold UV flame packages for evaluation purposes, and will sell the packages for about $400 in commercial production. Also, in February 1993, APA announced the first commercially available GaN solid-state detector of UV radiation. Other uses for these detectors include ozone monitoring, measurement and calibration of biomedical instruments, spectrometry, solar radiation measurement, fluorescence measurements, and tanning booth monitoring.

APA is also working on surface emitting lasers, UV light emitting diodes (LEDs), and short-wavelength optoelectronic integrated circuits based on AlGaN and GaN technology.

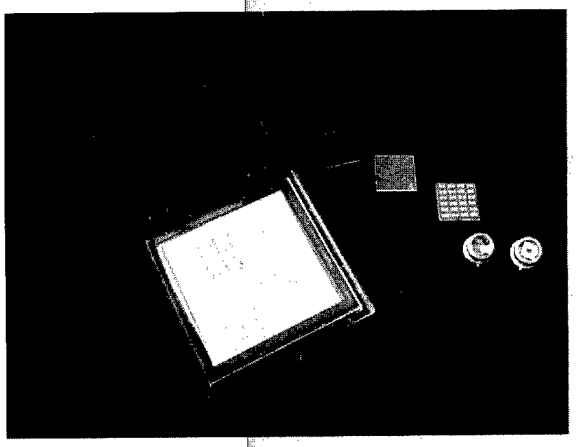
Advantages of AlGaN and GaN

Unlike competing materials, AlGaN and GaN semiconductors are chemically inert and stable over a wide temperature range. Furthermore, they have a large, tunable bandgap energy.

When used as UV detectors, the semiconductors do not respond to visible light, which means the detectors don't need filters to detect UV radiation in the presence of visible light. APA's UV detectors operate on low voltage (5 to 15 V bias) and produce a linear analog output over a large dynamic range. The responsiveness of the detector is fairly constant over the 200 to 365 nanometer spectral range. APA offers individual devices in standard TO5 transistor cases. Custom packages for specialized applications are also available.



Above *APA Optic's gallium nitride ultraviolet detector, which at 1 square millimeter is about 100 times smaller than your fingernail, mounted in a standard TO5 transistor case. APA Optics sells the UV detectors, either in this package or custom-designed, for monitoring flames in industrial processes that employ combustion, such as steel furnaces. Other uses of the detector include ozone monitoring, measurement and calibration of biomedical instruments, spectrometry, solar radiation measurement, fluorescence measurements, and tanning booth monitoring.*



Below *The steps in manufacturing APA's gallium nitride ultraviolet detectors. First, they are constructed on high-purity sapphire wafers (left). They are then cut into single elements (middle) and packaged in TO5 mounts (right). This is the first method to produce crystalline layers of gallium nitride suitable for general use.*

Technology to Watch

BMD Research Reaches a Milestone in Digital Optoelectronic Computing

In the drive to make faster, smaller computers, electrical engineers have developed a host of methods to pack more and more circuitry on an electronic computer chip. However, as engineers place more logic circuit elements, or gates, on a chip, the chips generate more heat and consume more power per unit area. As a result, heat removal becomes much more difficult. This problem forces researchers to develop more sophisticated methods of making efficient, multi-element processors for high-speed computing.

Because optical technology cuts the amount of heat a computer generates and the amount of power it consumes per gate, optoelectronics could spawn a new generation of faster, smaller computers. To take advantage of these benefits, OptiComp Corporation (Lake Tahoe, NV) has merged optoelectronics technology with electronic circuitry in a digital optoelectronic computing (DOC) prototype. OptiComp recently demonstrated this fully program-mable, 32-bit DOC prototype with the help of funding from the BMDO IS&T program and the Air Force's Rome Laboratory. These organizations funded this research for use in image processing, real-time signal processing, numerical analysis, and other computation-intensive areas.

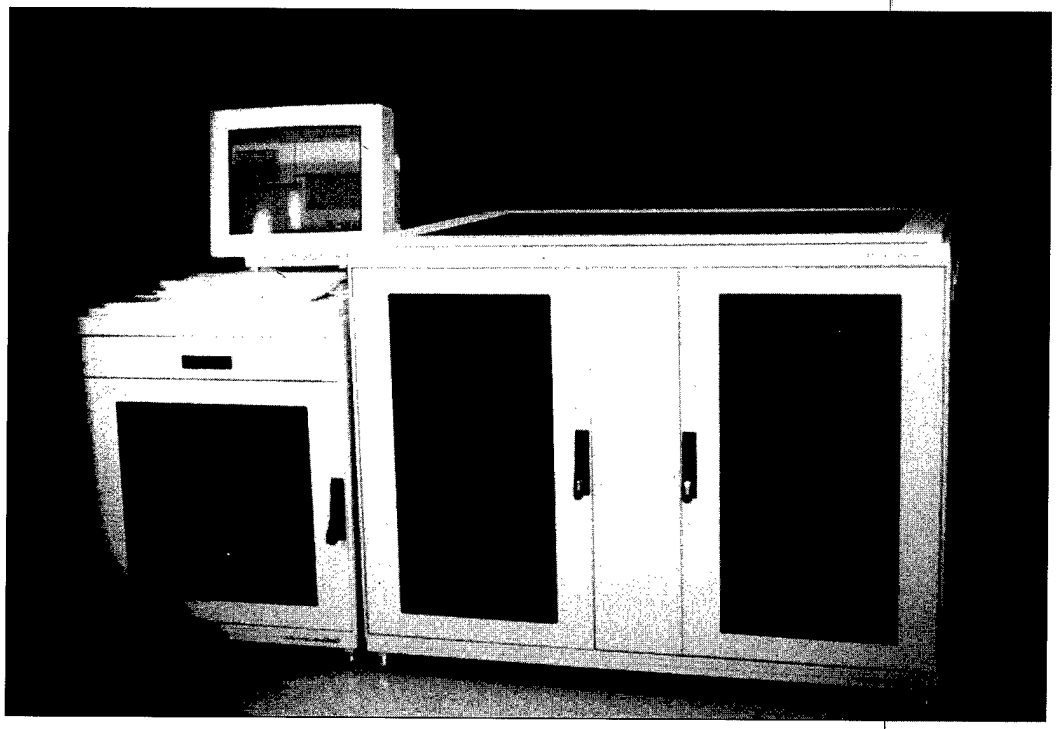
continued on next page

DOC Prototype Design

The phase one DOC prototype's digital architecture capitalizes on the inherent benefits of parallel optoelectronic computing, which include:

- High FAN-IN and FAN-OUT (which increases the number of free-space optical interconnects)
- Lower power consumption
- High algorithmic efficiency.

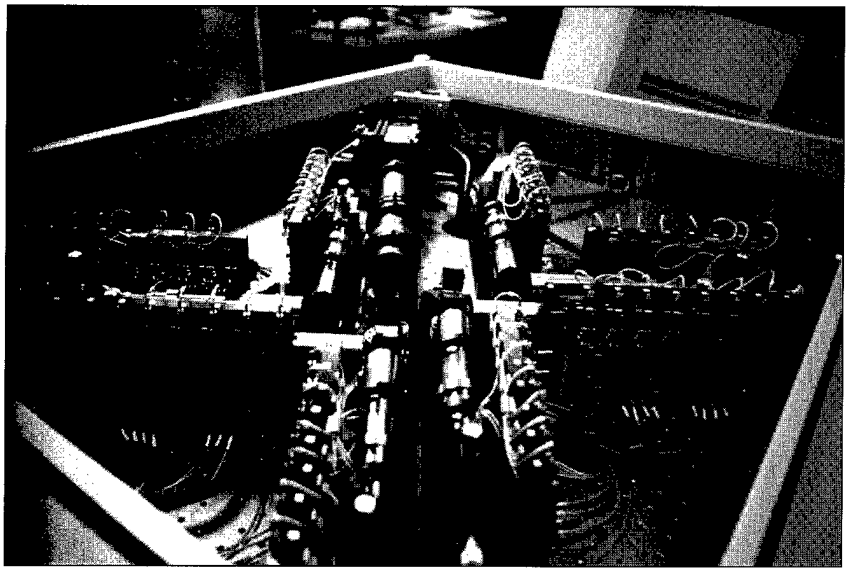
This prototype consists of two primary assemblies, the illumination assembly (Train A) and the modulation relay assembly (Train B), mounted on a 36-by-48 inch optical platform. Both assemblies operate at a wavelength of 837 nanometers, which is in the near-infrared spectrum, and are packaged in a portable optoelectronic cabinet. ➠



Above *OptiComp's Digital Optoelectronic Computing Prototype. In a recent demonstration, this fully programmable, 32-bit computer achieved peak speeds of nearly 10^{12} bit operation per second. Depending on the instructions used to guide these operations, this speed yields 10 million to nearly 13 billion 32-bit operations per second, comparable to today's electronic supercomputers.*

In OptiComp's demonstration, the DOC achieved peak speeds of nearly 10^{12} bit operations per second. Depending on the instructions used to guide these operations, this speed yields 10 million to nearly 13 billion 32-bit operations per second. The DOC prototype can achieve these speeds, which are comparable to those of today's electronic supercomputers, while consuming over 100 times less power per gate than computers that do not merge optoelectronics and electronics technologies.

OptiComp currently markets nine custom optoelectronic components developed as an outgrowth of this research, primarily to Federal and private laboratories. The company has also begun a phase two effort to design a next generation DOC. This 64-bit DOC will have more advanced interconnect technology and logic switching capabilities, which means it should provide 10 times more throughput than the phase one DOC. OptiComp has received follow-on support from the BMDO IS&T program and Rome Laboratory for this research, along with additional support from the Advanced Research Projects Agency.



Above *Inside the optoelectronic cabinet of the DOC prototype. This design has two primary assemblies, the illumination assembly (left) and the modulation relay assembly (right).*

Train A consists of:

- Eight individually addressable, eight-element laser diode array bars
- Eight high-speed electronic laser driver boards
- Eight sets of low spatial distortion, high numerical aperture, optical collimators, and 10x optical imagers
- A seven-element beam cube assembly.

Train B consists of:

- Two anamorphic optical relays, each with high-resolution and wide aperture
- A 64-channel spatial light modular (SLM) with 128 pixels of resolution per channel, providing a total of 8,192 pixels
- An integrated 128-element avalanche photodiode (APD) linear array, using multichip module technology
- Radio frequency (RF) electronics, SLM electronic drivers, and APD amplifiers.

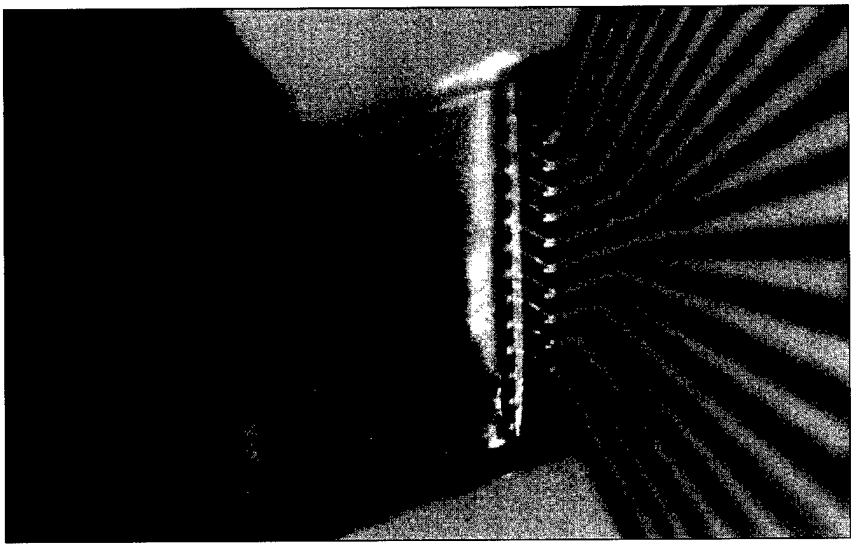
Technology to Watch

Surface Emitting Lasers Pave Way for Optical Computing Innovations

The next generation of computer and communications microcircuits will replace electrical signals with light waves. Because surface emitting lasers, with more light-producing surface area, are more easily mated to optical waveguides, they are more useful in opto-electronic circuitry and chip-to-chip configurable interconnects than traditional edge emitting lasers. Unfortunately, surface emitting lasers have been more difficult to make than edge emitting lasers.

David Sarnoff Research Center (Princeton, NJ), however, has developed a grating-surface-emitting (GSE) semiconductor laser that, according to Sarnoff researchers, makes it four times less expensive to produce 2-D laser arrays than now possible. Besides the GSE laser's applications in optoelectronic integrated circuits, which someday may be enormously lucrative, it could be used in free-space optical communications, ranging and fusing, optical recording, and optical printing.

Sarnoff Research Center developed the GSE laser for BMD laser radar applications, and is considering several options for developing a GSE laser product for commercial applications, including teaming with a manufacturing company.



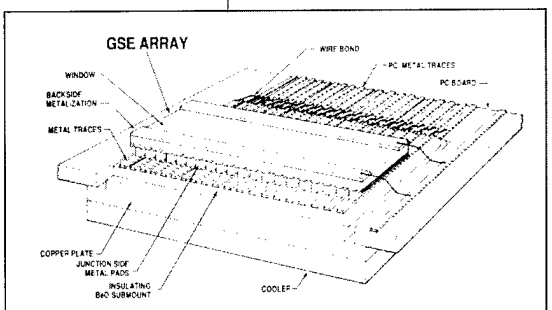
Above *A 100-element (10x10) 2-D grating-surface-emitting diode laser array. Surface emitting lasers, are more easily mated to optical waveguides and optoelectronic circuits than edge emitting lasers. As a result, they could be an important component in future optoelectronic integrated circuits.*

GSE Laser Design

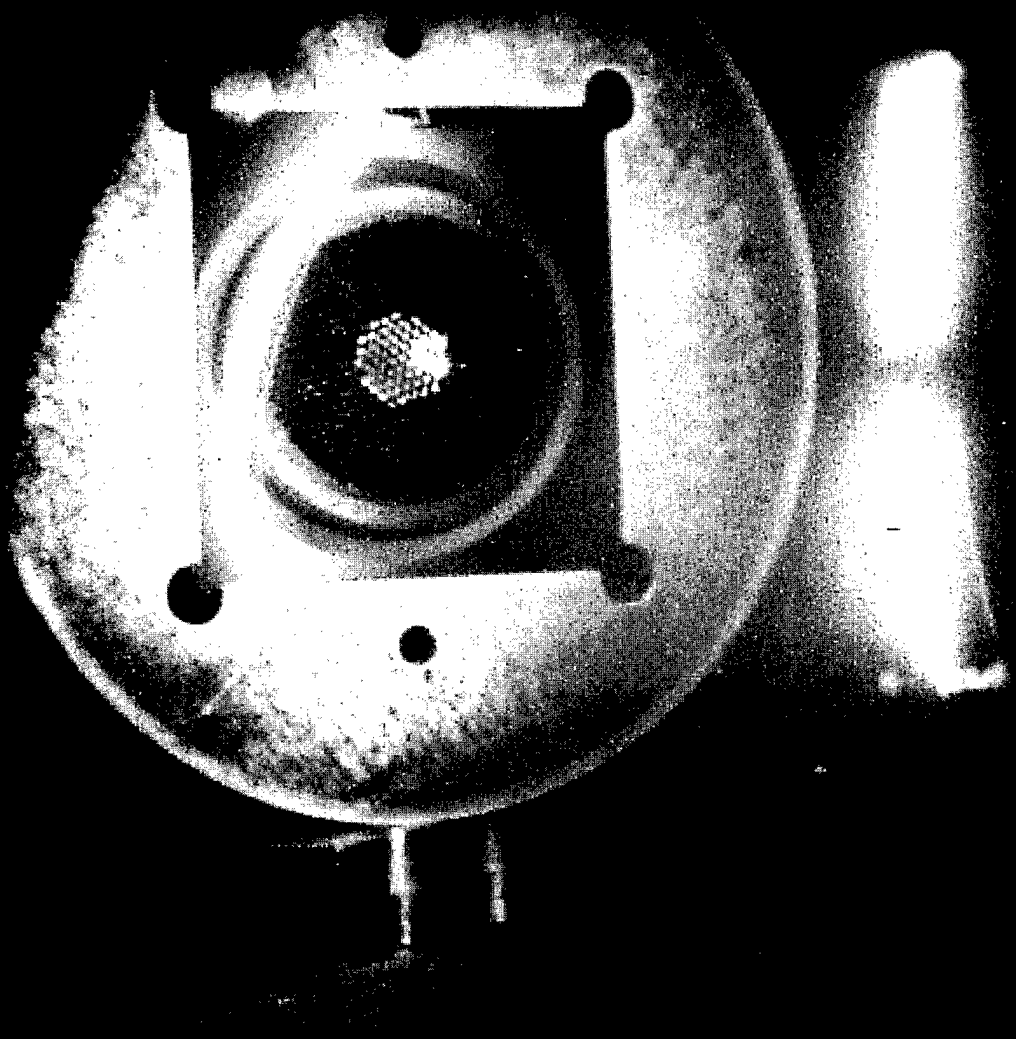
Sarnoff's GSE laser employs aluminum gallium arsenide as a semiconductor medium and uses localized patterned gratings as cavity reflectors, rather than cleaved facets. An electrical bias to the device provides beam steering.

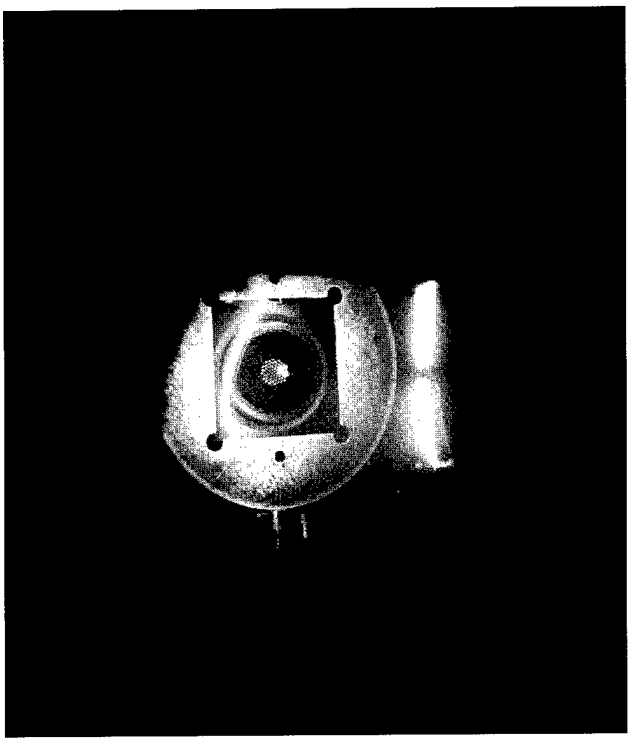
GSE lasers have shown continuous output powers of over 300 milliwatts in a single wavelength with high beam quality. These lasers demonstrate the performance required for some laser-based communications systems. Two-dimensional arrays have shown continuous wave output powers of 3 watts and greater than 30 watts under pulsed operation. This translates to a pulsed opwer density of 3.5 kilowatts per cubic centimeter, over three times that needed to pump solid-state lasers for laser radar applications.

Right *A schematic of a GSE array mounted on a beryllium oxide substrate and cooler. Sarnoff Lab's 2-D arrays have shown output powers of 3 watts continuous wave and greater than 30 watts (3.5 kW/cm²) under pulsed operation (100 nanosecond pulses at a 10 kHz repetition rate).*



GSE Array on BeO Submount and Cooler





Sandia Systems, Incorporated - Page 42

For years, precision optics have been made essentially the same way, with only incremental improvements: opticians first mold the basic form of the component and then repeatedly polish and test it until they reach the desired accuracy. Because this cycle is so labor intensive, it poses major barriers to deploying ballistic missile defenses, whose sensors and tracking equipment require extremely precise optics. New BMDO-sponsored technologies, however, are bringing optics makers close to completely bypassing this polish and test cycle. The result is less expensive, more precise optics that will benefit not just BMD systems, but also equipment used in such diverse areas as astronomy, computer chip manufacturing, and medical diagnostics.

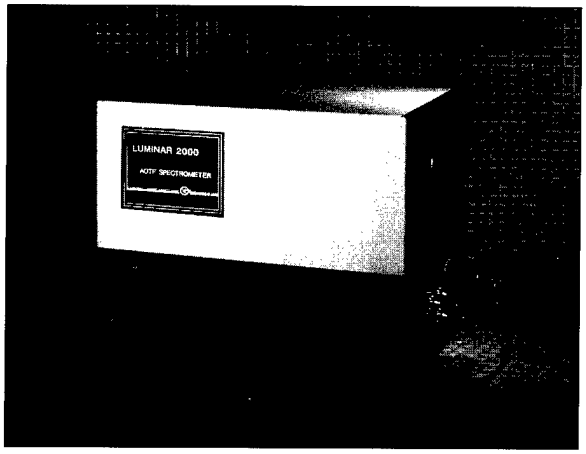
BMDO has also made important contributions in laser research. Investigated for tracking missiles, communications, and—in the case of a few high-powered laser systems—destroying missiles, BMDO-sponsored research has helped lasers become important commercial tools.

Acousto-Optics Build Multimillion Dollar Business

Due to the need to control laser beams in BMD systems, the BMDO SBIR program funded early research in acousto-optics technology (see sidebar). This funding has led to what is now a multimillion dollar product line for the Brimrose Corporation of America (Baltimore, MD).

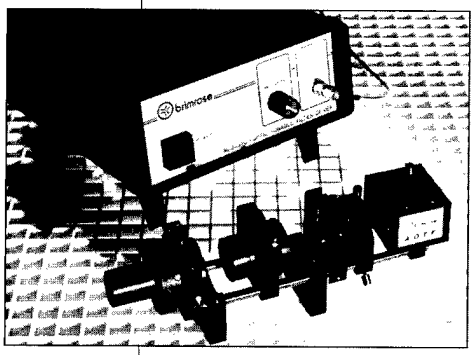
Foremost among Brimrose's acousto-optics products is the acousto-optic tunable filter (AOTF), which spectrally separates and filters light. Using the AOTF, Brimrose has developed a spectrometer that could be used for on-line quality control and analysis. A Florida company uses Brimrose's spectrometer to check the quality of its frozen orange juice. Brimrose has also demonstrated an AOTF-based spectrometer that can read changes in the body's calcium levels. With these calcium levels, doctors can better predict possible heart attacks, strokes, and other maladies. Anesthesiologists have also used the spectrometer to monitor gas composition and blood oxygen levels during surgery. Other uses include measuring pollution levels and monitoring the production of pharmaceuticals, petrochemicals, and polymers.

The AOTF also can be implemented in a microscope or telescope for visible, infrared, or Raman spectral imaging in scientific and medical applications. An AOTF-based noninvasive sensor can measure blood sugar levels using the near-infrared radiation spectrum. The system promises diabetics a painless alternative to their present need to monitor glucose by drawing blood samples several times a day. AOTFs will also serve as a wavelength division multiplexer (WDM) in the next generation all-optical communications network. An AOTF-based WDM can handle broadband signals in the 100 gigabit per second range.



Above *A spectrometer, built by Brimrose Corporation of America, that uses an acousto-optic tunable filter to spectrally separate and filter light. A Florida company uses this spectrometer to check the quality of its frozen orange juice. The spectrometer has many other uses in medicine, chemical processing, and pharmaceutical production.*

Below *An acousto-optic tunable filter (below) and the driver used to power it (above). The market for AOTFs is rapidly growing, and Brimrose now controls about 80 percent of this market.*



A Primer in Acousto-Optics

Acousto-optic devices control laser beam phase, amplitude, frequency, and angular direction by using ultrasound to alter the refractive index of an optical medium. Progress in acousto-optics has been stimulated by new fabrication methods for acousto-optic crystals and the piezoelectric transducers used to convert electrical energy to acoustical energy. In general, acousto-optic devices control laser light in three different ways: amplitude modulation, beam deflection, and frequency-shifting. In addition, AOTFs can be used to spectrally separate and filter incoherent broadband light.

Amplitude modulators, beam deflectors, and frequency shifters are used to modulate lasers in optical scanners, laser printers, optical deflectors, and optical switches. Brimrose estimates that markets for these traditional beam control devices are shrinking because internally modulated laser diodes are beginning to replace lasers that now require amplitude modulators. The market for AOTFs is rapidly growing, though, and Brimrose now controls about 80 percent of this market.

Two More Companies Find Riches in Acousto-Optics

Under a BMDO SBIR contract, Scientific Research Associates, Inc., or SRA (Glastonbury, CT), developed ultraviolet sensors that employ acousto-optic tunable filters (AOTFs). In 1989, Ciencia, Inc. (East Hartford, CT) spun off from SRA and developed AOTF-based sensor systems for BMD interceptors. Today, both companies sell AOTFs to commercial markets, where the devices serve in rugged, portable, low-cost spectrometers. These spectrometers are used in medical diagnostics, analytical instrumentation, environmental monitoring, chemical process control, and remote sensing.

Science Research Associates

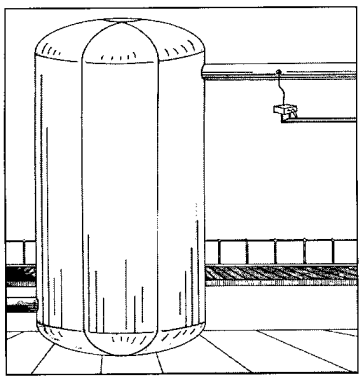
SRA primarily markets its AOTF-based sensors to semiconductor manufacturers, who use them for on-line process control. For example, one of SRA's AOTF-based sensors can monitor the chemical composition of the low-temperature plasmas used to deposit and etch integrated circuits. These sensors, which can be computer-controlled, will improve the speed and accuracy of semiconductor process and quality control systems.

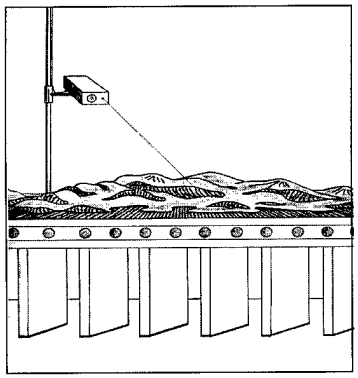
SRA has also developed AOTF-based temperature sensors to monitor chemical vapor deposition processes. Monitoring and controlling the crystal or substrate temperature during growth can increase manufacturing yields and reduce costs. The AOTF-based temperature sensor can measure temperatures ranging from 100° to 3000°C in a variety of processing reactors and crystal growth chambers.

Ciencia

Ciencia recently received a BMDO SBIR contract to develop a polymer material that can replace more commonly used crystals in AOTFs. Polymers are easier and cheaper to make than conventional crystals and provide uniformity and quality control during the manufacturing process.

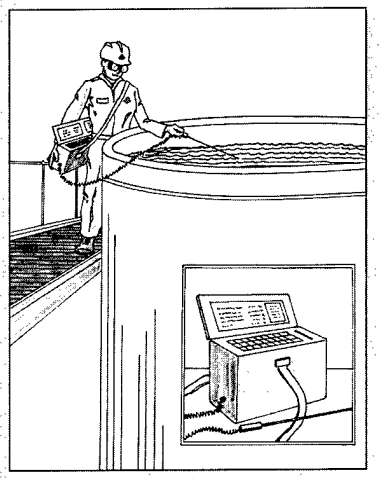
Ciencia, which has a patent pending for the polymer AOTF, is developing fiber-optic sensor systems to analyze chemical production on-line for the FMC Corporation. Ciencia also is developing a system that detects molds and other contaminants in citrus fruit for Sunkist Growers, Inc. Furthermore, the company has received money from the State of Connecticut Department of Economic Development to exploit the AOTF for medical uses and is developing a portable spectrometer for the analysis of biological fluids for the National Institute of Mental Health.





Acousto-Optic Polymers

Acousto-optic devices use ultrasound to alter the refractive index of an optical medium, typically a crystal. By applying mechanical stress or electric fields to Ciencia's polymers, the speed at which light passes through a substance changes for different frequencies of light and different directions. This phenomenon, known as birefringence, allows the AOTF to separate light into different colors. Unlike an ordinary monochromator, the AOTF can be tuned electronically, so it has no moving parts. In addition to tuning, the polymeric device can produce spectrally resolved images.



Above *An artist's concept of a portable analyzer used for process analysis and environmental monitoring. Ciencia's polymer-based acousto-optic tunable filters would be used in such a device. The company is currently developing fiber-optic sensor systems to analyze chemical production on-line for the FMC Corporation and a system that detects molds and other contaminants in citrus fruits for Sunkist Growers, Inc.*

Left *The figure in the far left depicts an on-line, real-time process analyzer; the figure next to it shows a remote laser sensor also used for process analysis and environmental monitoring.*

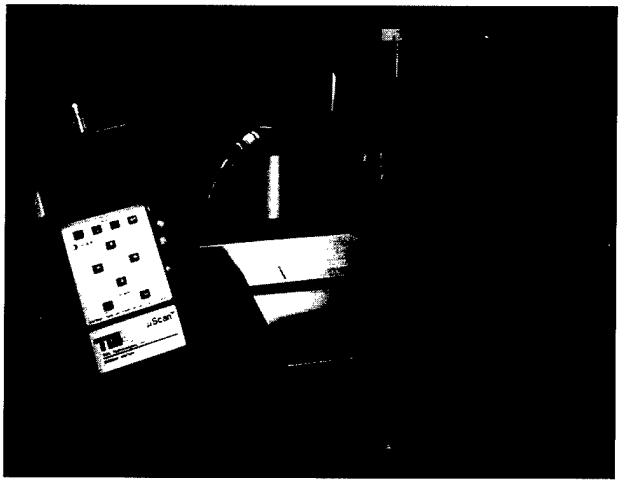
BMD Research Spurs Growth of Optics Start-Up

With the help of BMD spinoffs, TMA Technologies, Inc. (Bozeman, MT) has grown from 6 to 40 full-time employees, with total sales of over $3 million in 1992. In fact, *Inc.* magazine cited TMA as one of the 500 fastest growing companies in the country in 1990.

TMA's growth started in 1986, when Oak Ridge National Laboratory awarded TMA its first big contract to build a scatterometer for measuring high-quality BMD optics. Other BMD and defense contracts followed, leading to a full product line of commercial scatterometers. The company's first product was a line of research scatterometers known as CASI™ (for Complete Angle Scatter Instrument) that TMA has delivered to universities, national laboratories, and industries in the United States and abroad. Soon after that, TMA developed two more commercial products: μScan® and SurfMap-IR™.

μScan® is a hand-held scatterometer primarily designed to inspect aircraft windows, but has also been used to measure the surface roughness of optical components and finely machined parts. SurfMap-IR™ is a contamination device that measures the presence of hydrocarbons for manufacturing applications in aerospace, automobiles, and films and coatings. TMA also builds complex one-of-a-kind scatterometers, such as the system that Wright-Patterson Air Force Base uses to characterize the surface of stealth aircraft skins and a broadband out-of-plane scatterometer that NASA will use for ozone mapping.

This success, though, may just be the beginning for TMA. The company is now using its expertise in surface characterization to move into a much bigger market: industrial alignment and measurement. TMA has four systems in various stages of development for this product line: an Auto-Collimating Alignment Laser System, a Gap & Mismatch System, a Camera Aided Positioning System, and a Dynamic Monitoring System. TMA has already introduced the Auto-Collimating Alignment Laser System, which is the most accurate laser alignment system on the market, and plans to introduce the Gap & Mismatch System sometime this year.



Left *μScan®, a hand-held scatterometer used to inspect aircraft windows and measure the surface roughness of optical components and finely machined parts. μScan® is one of a full line of scatterometers and industrial measurement devices that TMA markets as the result of BMD-sponsored research.*

Scatterometers Measure Surface Roughness

Optical and mechanical systems require surface roughness measurements to eliminate the following problems:

- ***Excess Light Scatter.*** Scatterometers directly measure the light scatter at certain wavelengths of sensing optics, imaging optics, laser optics, and other systems. The amount of light scatter at the operating wavelength must be precisely limited for the optics to work properly.

- ***Mechanical Malfunctions.*** In mechanical systems, surface roughness can lead to malfunctions. For instance, if a computer disk is too smooth, the read/write head may bind to the surface, but if the surface head is too rough, the head may not be able to fly over the disk cushion properly. Also, excess surface roughness in engine machine parts can lead to high levels of frictional heating, which can cause engine damage or failure.

- ***Environmental Instability.*** With a high surface roughness, products have more surface area exposed to contaminants that cause corrosion, excess wear, and other defects. Thus, they are more susceptible to adverse environments (temperature, humidity, hostile chemicals, etc.).

- ***Cosmetic Defects.*** Cosmetic defects lower the quality a customer perceives in a product, and cut sales substantially. For example, a rough paint finish may not affect car performance, but few customers will want to buy the car.

Improved Mirror Shaping Techniques to Correct Hubble Optics

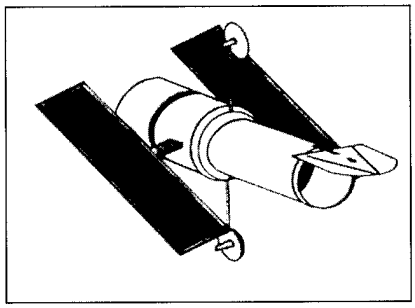
Optical devices often work best if made in a very complex shape. Because the shape is tailor-made for an application, these aspheric mirrors give optical systems better image resolution and wider field of view than standard spherical-shaped mirrors. This means optical systems can use fewer, smaller, and lighter components.

The catch is that aspheric mirrors are usually much more difficult to produce than standard mirrors; because of their complicated shape, skilled opticians typically build and polish aspheric mirrors and lenses by hand. To eliminate this pitfall, BMD started the Aspheric Surfacing Technology (AST) program at the Air Force's Rome Laboratory. So far, automated surfacing and metrology techniques developed under the AST program have cut the manufacturing time of aspheres by a factor of three.

The primary contractor in this project, Tinsley Labs (Richmond, CA), has used many of the techniques developed in this program to build corrective optics for NASA's Hubble Space Telescope and the main optical elements for the Wide-Field Planetary Camera (see sidebar). Aspheric surfacing technology also could be used to fabricate optics for medical diagnostic instruments, microcircuit manufacturing equipment, and sensors (both space-based and terrestrial).

The Hubble Connection

In BMD's AST program, Tinsley Labs improved technology for precision machining, computer-controlled optical surfacing, high-speed profilometry, and phase measuring interferometry. Hughes Aircraft Company contributed performance simulation, testing, and systems design expertise to the program. In correcting the Hubble Space Telescope's optics, Tinsley Labs has extensively used the computer-generated holograph (CGH) interferometer, a result of its work in high-speed profilometry for BMD. Tinsley also refined its surfacing technology during the AST program and used those advancements for the NASA programs.



Right *Aspheric mirrors (above) and a drawing of the Hubble Space Telescope (below). Aspheres give optical systems better image resolution and wider field of view, but are much more difficult to manufacture than standard spherical-shaped mirrors. BMD's Aspheric Surfacing Technology program has cut the manufacturing time of aspheres by a factor of three.*

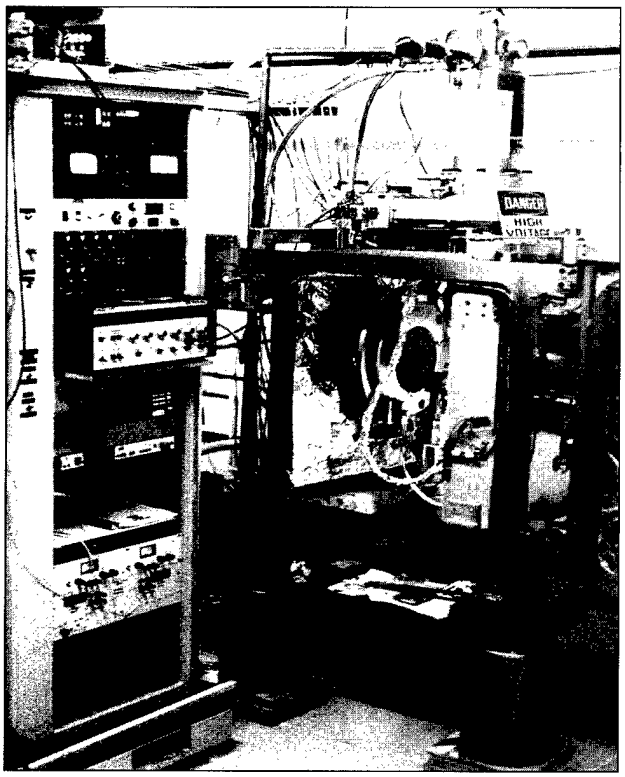
Start-up Company

New Company to Commercialize Optics Manufacturing Technique

A new optics manufacturing technology called ion beam figuring allows opticians to make lenses and mirrors with greater precision and fewer worker-hours than conventional optical finishing techniques (see sidebar). This development, which came from BMDO-sponsored research at the University of New Mexico, has resulted in a spinoff company, Sandia Systems, Inc. (Albuquerque, NM).

Sandia Systems is negotiating a license of the technology with the University of New Mexico, and has received about $700,000 in government and commercial research contracts, including a BMDO SBIR contract to investigate ion milling on chemical vapor deposited silicon carbide. Sandia Systems is trying to address more practical issues regarding commercialization during these research projects.

University of New Mexico researchers have also served as consultants to the Eastman Kodak Company while Kodak designed and built an ion beam figuring facility used to correct large mirror segments.

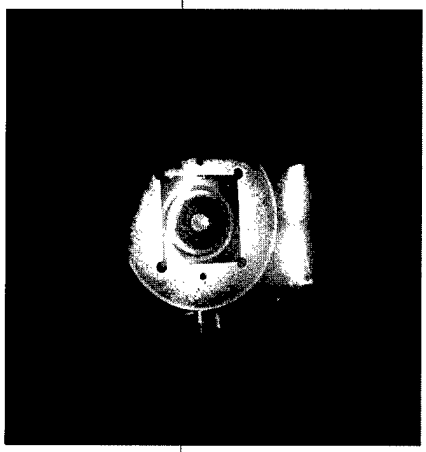


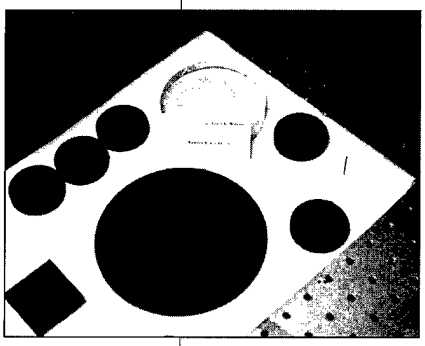
Above *An ion beam figuring machine, from a distance (left) and close up (right). This technology, which came from BMDO-sponsored research at the University of New Mexico, has resulted in a spinoff company, Sandia Systems, Inc.*

Right *Mirrors polished using ion beam figuring. The technique can produce optics with a precision of 600 ångströms and better, and can enhance the manufacture of all types of optics 30 cm and larger in diameter.*

Ion Beam Figuring

When producing unconventionally shaped optics using traditional optics figuring techniques, opticians must repeatedly polish and examine the optics. Each step requires more and more labor to reach the desired accuracy, which means that the final polishing stage is especially difficult to complete. In contrast, ion beam figuring can reach the desired accuracy with only one or two passes. Ion beams provide this advantage because they allow precise numerical control over how much material they remove. As a result, ion beam figuring can produce optics with a precision of 600 ångströms and better, and can enhance the manufacture of all types of precision optics 30 cm in diameter and larger.





SBIR Moves Firm From the Garage to Wall Street

SBIR contracts have helped propel Excel Technology, Inc. (Holbrook, NY) from a one-man operation to a $20-million company. For the BMDO SBIR program, Excel developed a tunable titanium-sapphire laser, the world's first all solid-state tunable laser (see sidebar). Excel has been selling this laser to scientific, medical, and consumer markets since April 1989.

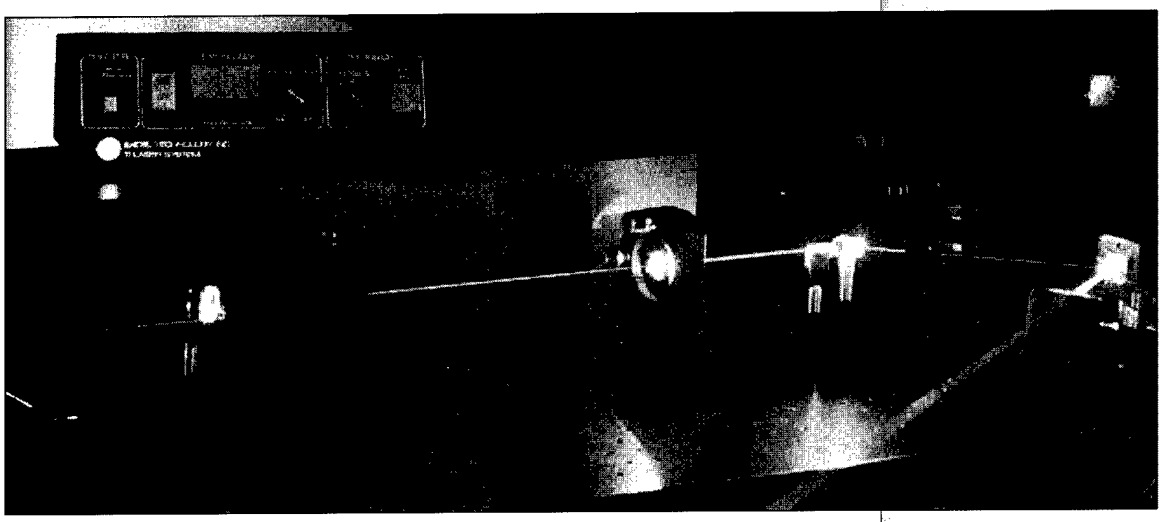
Scientific applications of the laser include spectroscopy and semiconductor research; medical applications include photodynamic therapy, laser surgery, and diagnostic imaging; and industrial applications include material processing, color laser printers, color copiers, color video projection, color bar code scanners, and optical data storage.

Excel has a long history of SBIR success, with other development support coming from the NASA, NIST, and NSF SBIR programs. With this research base, Excel has built a $20-million company through a 1991 Wall Street initial public offering, through which the company raised $4 million, and a 1992 acquisition of a large laser manufacturing firm. In addition to the titanium-sapphire laser, Excel markets two solid-state dental lasers for treating soft tissue.

World's First All Solid-State Tunable Laser

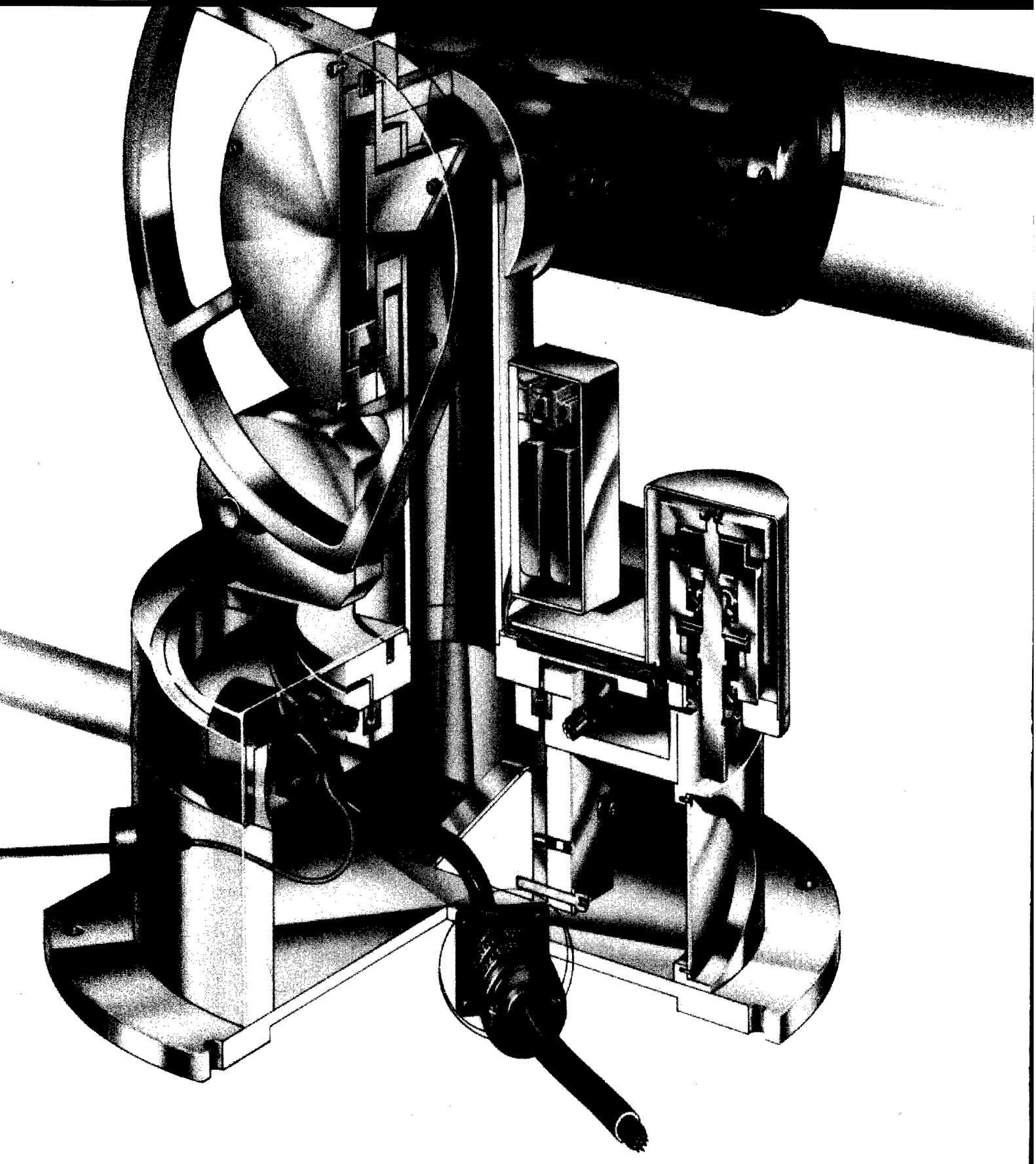
Excel's laser combines a durable solid-state Nd:YLF (neodymium: yttrium-lithium-fluoride) pump laser with an efficient, tunable Ti:Sa (titanium-sapphire) laser. The Nd:YLF pump replaces less durable and less effective gas lasers, while the Ti:Sa laser eliminates the power fluctuation and downtime that occurs when using dye lasers.

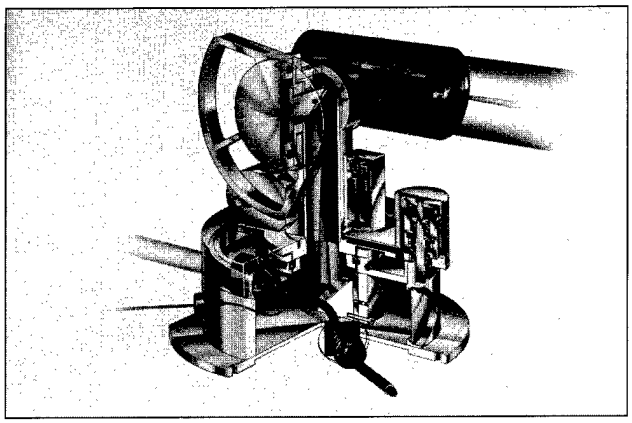
The laser has a tuning range of 670 to 1070 nanometers and an average power of 350 milliwatts. Other key operational capabilities include a repetition rate of one kilohertz, which increases the signal-to-noise ratio 100-fold over the standard 10 hertz system; and a peak power of 25 kilowatts, which provides frequency-doubling of the output wave to allow tuning from 335 to 535 nanometers.



Above *Excel's all solid-state tunable laser. The company has been selling this laser to scientific, medical, and consumer markets since April 1989.*

Manufacturing





Sagebrush Technology, Incorporated - Page 46

In today's world of global economic competition, American companies must continually increase productivity to stay profitable. New technology, while not the only solution to this problem, is a key ingredient. BMDO has sponsored research in several areas that can help American manufacturing become more productive. For example, BMD systems require precise pointing and tracking technology to locate and destroy ballistic missiles. Software required for this activity is readily adaptable to flexible automated manufacturing; also, precise mechanical devices developed to control BMD systems can provide similar benefits on the manufacturing floor.

But no matter how much new technology is developed, people must run manufacturing operations; the more these people know, the more productive they can be. This need for better informed people led BMDO to establish manufacturing incubators, called Manufacturing Operations Development and Integration Laboratories (MODILs), to help American businesses gain expertise in new manufacturing systems. While BMDO established MODILs to help American companies produce BMD components more efficiently and at a lower cost, the MODILs focus on "leap-frog" solutions that are also relevant to commercial manufacturing problems.

The Roto-Lok® Rotary Drive: Positioning for the Future

For well over a century, the gear has been the workhorse of the industrial era. By transmitting torque, changing rotation speeds, or converting rotary motion to linear, the gear plays a key role in operating or manufacturing almost any product imaginable. But with advances in electronics technology over the past few decades, a new era in technology has begun. Today, electronic-based controllers can precisely dictate mechanical movements, but the gear can only respond with limited precision. This limitation occurs because gears' meshing teeth must have a slight amount of play to work properly.

The Roto-Lok® Rotary Drive, a new device for coupling a drive motor to a load, has bypassed this limitation. As a result, Roto-Lok technology, which was developed by Sagebrush Technology (Albuquerque, NM), may soon replace precision gears in coupling applications requiring limited rotation.

The Roto-Lok drive was originally designed to control astronomical telescopes, which require precise pointing of large, heavy structures. The BMDO Laser Communications program, however, provided key support to develop the drives into high-visibility products. In the LaserCom project, Sagebrush developed a Roto-Lok drive to control the precision angular alignment of laser beam transmitters and receivers in a communications network. The drive also serves as the azimuthal

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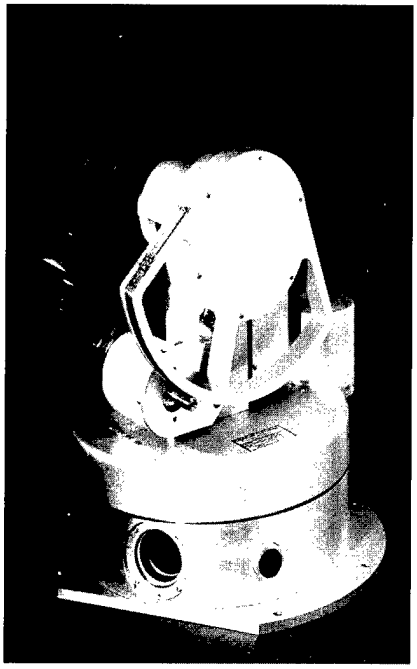
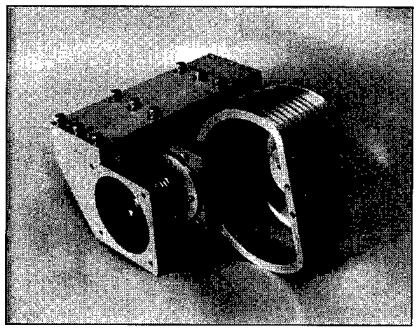
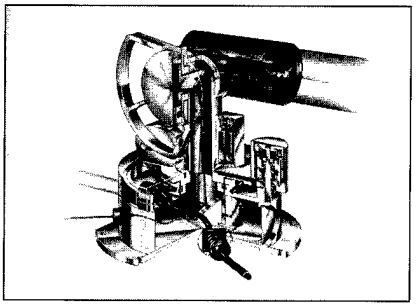




Above *A Roto-Lok® Rotary Drive. Sagebrush Technology has developed drives that can couple a drive motor to loads as tall as 50 m or as small as 1 cm, and as heavy as 5 million kg or as light as 10 g.*



Above and Right *A photograph and schematic of a BMDO satellite communications laser. Because the Roto-Lok® drive can control the angular alignment of laser beam transmitters and receivers with greater accuracy than precision gears, it is a key component in this system.*

Key to Roto-Lok® Performance: No Backlash

To transmit power, Roto-Lok® drives use cables wrapped in a figure-eight pattern around two closely spaced wheels. The friction of the cables carries torque from a powered wheel (capstan) to a driven wheel (drum). The drive maintains precision by employing the averaging effect of many cables working in parallel. By sharing the load, the cables average the rotation rate so that any imperfections, dirt, or other slight irregularities on the drum do not affect the drive rate. Roto-Lok drives also have much higher stiffness than chains and drive belts. This stiffness is maintained by springs at the end of each cable—which provide tension throughout the length of the cable—and close spacing of the wheels— which keeps the cables close to the cylinder where tension is at a maximum.

Spring-loaded cables also eliminate one of the most difficult design problems in precision gears: backlash—the clanking of gears caused by play between the teeth. Backlash reduces pointing accuracy because vibrations from this clanking affect the motion of the entire system. Backlash also reduces transmission efficiency because energy is dissipated in the vibrations.

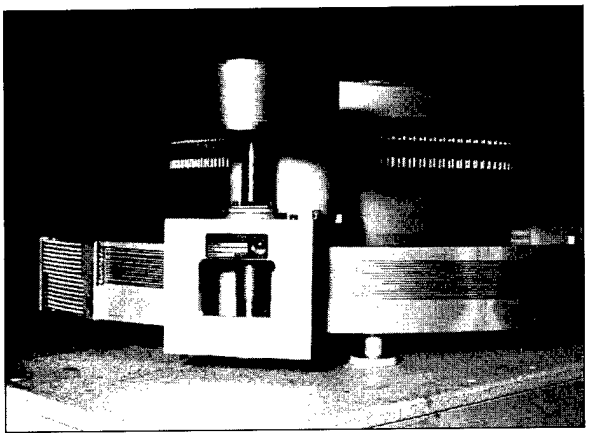
While engineers can cut backlash in gears by eliminating the space between teeth, this increases gear friction. Higher friction, in turn, increases wear and reduces ➠

instrument drive for sensors on BMDO's High Altitude Balloon Experiment, and Sagebrush is negotiating a contract with BMDO to use Roto-Lok drives in airborne tracking systems.

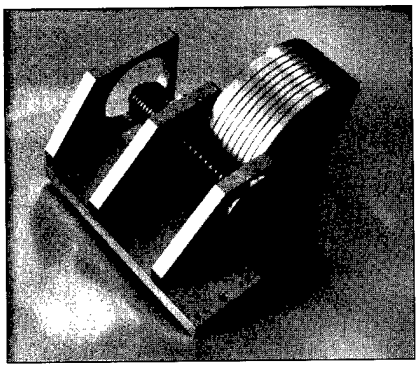
Sagebrush designs custom Roto-Lok drives for a variety of applications and has developed drives that can handle payloads as tall as 50 m or as small as 1 cm, and loads as heavy as 5 million kilograms or as light as 0.01 kilograms. The next major step for Sagebrush is to enter high-volume markets. As a first step in this direction, Sagebrush was recently awarded a contract to manufacture an industrial rotator that will be the first such standard product. This rotator will provide the torque and precision needed to position large precision grinders, such as those used in computer-numerically-controlled (CNC) machines to produce high-quality optical lenses.

With further growth in this direction, other possible applications include drives for automated appliances, antenna positioners, damper actuators, machine tools, and home satellite dishes. The Roto-Lok drive also could be used in robotic joints, valve actuators, exercise equipment, heating dampers, chairlifts, turntables, automotive steering, and surgical manipulators.

To satisfy such a broad range of applications, Sagebrush intends to join forces with a large company that has an existing marketing and distribution network for industrial machinery.



Left *A Roto-Lok®-based industrial rotator. This rotator positions large precision grinders, such as those used in computer-numerically-controlled machines to produce high-quality optical lenses.*



Left *The Roto-Lok® Rotary Drive. The lines on the two semicircular wheels are cables, which carry torque from the smaller, powered wheel (capstan) to the larger, driven wheel (drum). By using the averaging effect of many cables, the drive maintains unparalleled precision.*

gear lifetime. As a result, engineers have worked for centuries to find the best balance between minimal backlash and minimal friction for each gearing application. This effort has led to countless complicated gear designs that are often difficult to manufacture.

In the Roto-Lok technology, springs provide the cable tension needed to eliminate backlash. With no measurable backlash, the drive has greater positioning accuracy (less than 1 microradian), operates more efficiently (greater than 98 percent efficient), and runs more quietly than precision gears. In addition, the springs are designed to accommodate wear and keep the cables constantly at their design tension. As a result, the Roto-Lok drives do not degrade with use, as gears do, and have a lifetime of more than 10 million cycles. Finally, the Roto-Lok drive is made of simple circular parts that are easy to manufacture for any application.

These benefits also result in lower costs, both upfront and during operation. Roto-Lok's comparative ease-of-manufacture reduces the initial cost, while longer system lifetime and lower maintenance requirements cut operational costs. Perhaps most important, the Roto-Lok drive's increased efficiency, accuracy, and torsional stiffness means that systems employing them can drive loads with lighter, less powerful torque motors than precision gears.

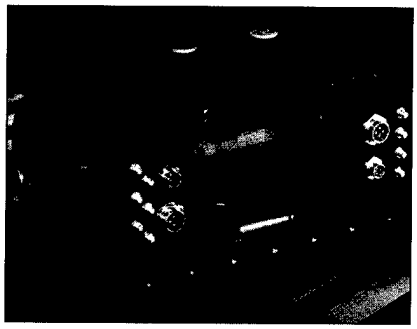
SatCon Moving Up

In January 1993 SatCon Technology Corporation (Cambridge, MA) completed an $8.8 million initial public stock offering to raise capital needed to introduce active motion control products to the market. Active motion control technology—which mimics how the human eye, brain, arm, and hand interact to sense position, apply force, and correct position—has a broad range of applications in manufacturing, automobiles, medicine, or any other area where external forces must be controlled. To date, SatCon has entered two partnerships to develop commercial active motion control products, one with Chrysler Corporation and one with Advanced Medical Systems, Inc. (AMS).

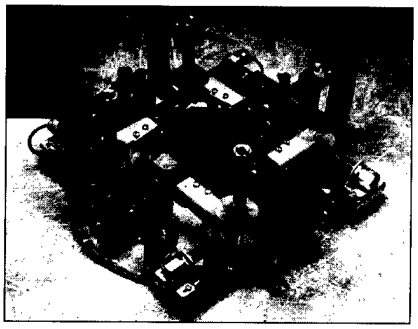
In the first agreement, SatCon will team with Chrysler to develop innovative drive train components employing active motion control technology. With these components—which include advanced electronic computation and power technology—drive trains of the future will be less expensive, lighter, more energy efficient, and more environmentally friendly.

In the second agreement, SatCon and AMS have formed a joint venture to develop, manufacture, and market an advanced heart pumping system that can be used for cardiovascular circulatory support and hemodialysis. For its part, SatCon will develop and manufacture the magnetic actuation, control, and sensing subsystems, while AMS will contribute its proprietary cardiovascular technologies and biomedical components. AMS also will determine clinical efficiency, perform clinical testing, and develop Food and Drug Administration protocols. The SatCon-AMS blood pump should be much smaller, more portable, and more reliable than existing devices.

The BMDO SBIR program funded much of SatCon's initial research in active motion control, with additional funding from NASA and other Department of Defense programs. BMD systems can use this technology to eliminate vibration in pointing and tracking systems and for more efficient and reliable flywheel energy storage systems and compressors. Other development efforts at SatCon will center on vehicle actuation systems, magnetic bearing machinery, vibration isolation and absorption systems, and microsensors.



Above *A refrigeration compressor that employs magnetic bearings. By eliminating friction, noise, and vibration, magnetic bearings can increase system efficiency and lifetime while cutting weight.*



Above *A vibration isolator. Systems such as this employ magnetic suspension to provide precise motion control in automotive suspension systems, precision manufacturing, and optical stabilization.*

Active Motion Control Applications

■ ***Magnetic Bearings.***
Magnetic bearings eliminate friction, noise, and vibration in rotating parts. For example, SatCon is involved in a BMDO SBIR project to develop a refrigeration compressor that employs magnetic bearings. By eliminating friction, magnetic bearings increase compressor lifetime and efficiency and reduce system mass. Magnetic bearing technology also can increase the efficiency and reduce the mass of flywheel energy storage devices used in hybrid automobiles. Other applications include data memory devices, machine tools, and turbine engines.

■ ***Vibration Absorbers.***
Absorbers use a vibrating mass to cancel noise and vibration. Potential applications include reducing aircraft vibration and quieting home appliances, machinery, and military equipment. Also, SatCon's absorbers could enhance the performance of standard shock absorbing systems currently used in automobiles.

■ ***Active Struts.***
Struts expand and contract to provide precise motion control. Potential applications include automotive suspension systems, optical stabilization, and vibration isolation for integrated circuit and other manufacturing processes requiring vibration free environments.

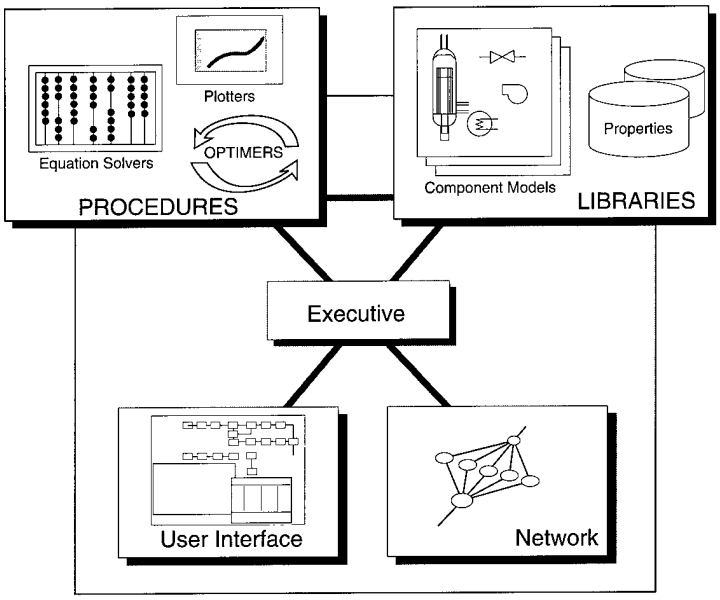
■ ***Microsensors.***
Ranging in size from 10 microns to a few millimeters, microsensors are made of silicon and installed on silicon chips to measure rotation, vibration, and magnetic field. The devices can be used to measure noise and vibration in military and commercial aircraft, automobiles, and other systems.

Software Simulator to Spur Manufacturing Gains

Argonne National Laboratory has attracted industry interest for developing agile manufacturing software systems with a program known as General Purpose Simulator (GPS). Because agile manufacturing systems rely on flexible manufacturing processes that can quickly respond to changing customer preferences, they represent the next leap forward on the factory floor. Argonne developed GPS during several BMD-related projects and other energy-related programs.

GPS, named for its versatility, allows programmers to develop computer models quickly. These models represent systems by linking component processes through a flow of some sort of information; for example, a computer system can be modeled by the flow of data between computers or a cooling system can be modeled by the flow of gas between heat exchangers.

In using GPS for agile manufacturing, factory designers could quickly model the most efficient manufacturing systems and produce the software needed to operate the automated machines used in these systems. An exchange associate to Argonne has studied the feasibility of using GPS for flexible manufacturing with good results, and the Argonne Technology Transfer Center is now working with the automotive industry to form a factory automation consortium based on GPS technology.



Above *General Purpose Simulator's precompiled objects. These objects accelerate system modeling by eliminating compiling time after each iteration of a model. GPS Executive, the underlying control language of the simulator, governs the use of precompiled objects.*

Control Language and Object-Oriented Programming Accelerate Modeling

With the GPS, researchers assemble the system to be simulated from standard, validated software parts (objects). These objects represent component models, data, and procedures for operating the system. Multiple instances of an object may be created, where each type of object retains its underlying character but uniquely responds to the environment in which it is placed. Object-oriented approaches of this sort promote software reuse, which in turn makes simulations easier to produce. Argonne researchers have also created an X-Windows-based graphical user interface, GPSTool, to facilitate system design. GPSTool allows researchers to manipulate objects through point and click commands.

The heart of GPS is the GPS executive—an underlying control language used to define systems and control their execution. The GPS executive language is interpreted rather than compiled, but makes calls to fully optimized, precompiled objects. This approach eliminates the compile and load steps between simulation prototypes, and thus speeds the cycle times during the iterative process of developing simulations.

GPS has already shown its versatility in three BMDO-funded simulations: one of a parallel computing architecture, another of a space nuclear power system, and one of a propulsion system. Working for other agencies, Argonne has used GPS to model fuel cells, fusion processes, and solar energy systems.

Partners w/Industry

Manufacturing Operations Development and Integration Laboratories

When producing something as technologically challenging as a missile defense system, developing new gadgets is not enough. Someone has to make them. To make sure that the United States will be able to do both when the time comes, BMDO set up a series of incubators that can help industry cut the cost, increase the quality, and speed up the manufacturing of BMD systems. To do so, these incubators, known as Manufacturing Operations Development and Integration Laboratories (MODILs), search for new technology developments from academia, industry, and government (in this country and abroad) to test and integrate on the manufacturing floor. This mission provides university, industry, and government participants with the chance to gain experience using unproven technologies in a real-world setting. Because the MODILs focus on enabling technologies that can be used in both defense and commercial manufacturing, they provide one of the most effective, face-to-face technology transfer tools in the BMD program. BMDO funded the following four MODILs:

■ ***Survivable Optics MODIL.*** Located at Oak Ridge National Laboratory (Oak Ridge, TN), the Survivable Optics MODIL began operation in 1988; its focus is on manufacturing mirrors and baffles, and developing in-process metrology techniques. The heart of the Optics MODIL is the Productivity and Validation Test

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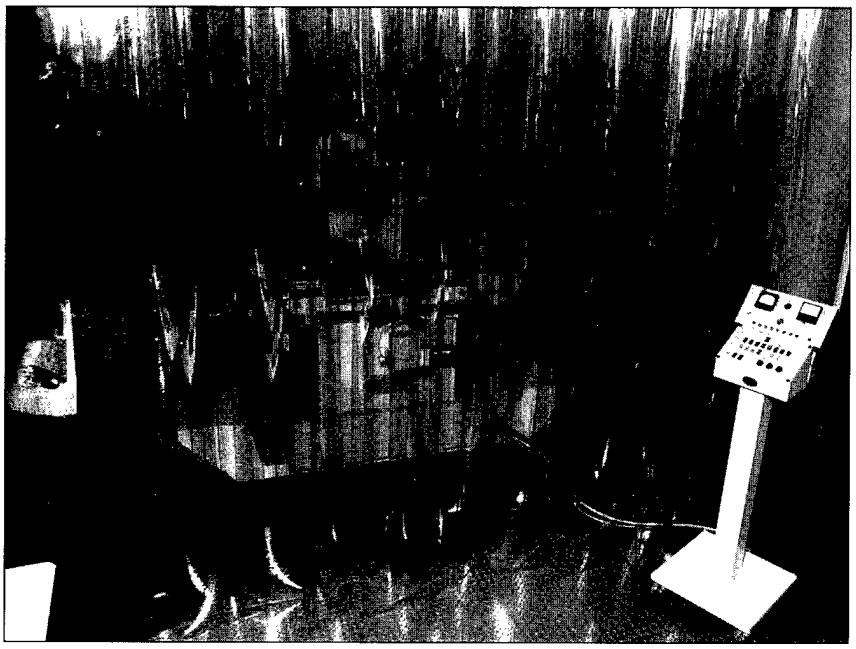


Above *A modular manufacturing cell. The plastic drapes and other innovations allowed the BMDO Optics MODIL to build an optics manufacturing floor that provides precise control of temperature, humidity, and other environmental conditions, all for considerably less money than required to build a completely new cell.*

CRADAs at the Survivable Optics MODIL

As the oldest of the four MODILs, the Survivable Optics MODIL has the longest track record of working with industry. So far, the facility has signed over six CRADAs, including the following:

■ ***Ductile Regime Grinding of Reaction-Bonded Silicon Carbide Substrate Mirrors.*** In general, high specific stiffness and attractive thermal properties make silicon carbide viable for engineering ceramics applications. To make reaction-bonded silicon carbide (RBSiC) more competitive in the marketplace, though, quicker, more accurate methods of figuring the material are needed. Therefore, United Technologies Optical Systems is working with the Optics MODIL to determine the optimum grinding parameters for manufacturing figured optical surfaces from its RBSiC material. The principal research will be carried out at the MODIL's Productivity Validation Test Bed (PVTB), which houses single-point diamond turning, ductile grinding, ion milling, and precision metrology capabilities.

■ ***Advanced Manufacturing Technology Validation for Precision Optics.*** In this CRADA, Martin Marietta Missile Systems is working with the Optics ➠

Bed, a production floor laboratory where MODIL users can learn firsthand how advanced optics manufacturing systems can be used in their own facilities. The Optics MODIL also hosts a series of industrial briefings and focused workshops designed to incorporate industrial input into the MODIL's slate of technology programs.

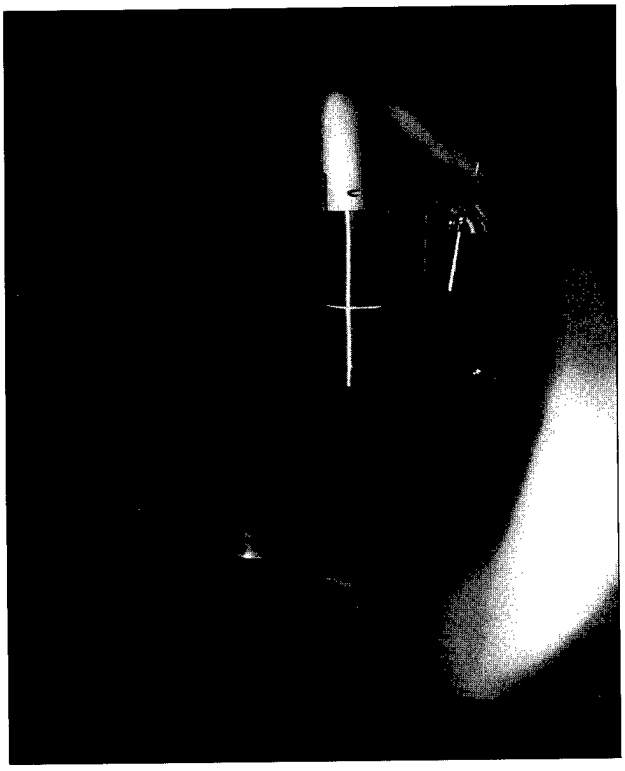
■ ***Electronics and Sensors MODIL.*** Located at Sandia National Laboratories (Albuquerque, NM), the Electronics and Sensors MODIL received its first funding in 1990, but did not become fully operational until 1992. Its focus is on manufacturing radiation-hardened microelectronics and advanced infrared detectors, and developing in-process control technology.

■ ***Software Producibility MODIL.*** Located at the National Institute for Science and Technology (Gaithersburg, MD), this MODIL began operation in March of 1992. Its mission is to encourage software reuse, promote the transfer of software for BMD use, and promote the development of new computer-assisted software engineering (CASE) tools.

■ ***Spacecraft Fabrication and Testing MODIL.*** Located at Lawrence Livermore National Laboratory (Livermore, CA), the Spacecraft MODIL began operation in November 1991. Its mission is to spur developments in integrated manufacturing software, precision machining, and lightweight structure manufacturing processes.

Depending on their needs, participants can gain know-how from the MODILs by entering a Cooperative Research and Development Agreement (CRADA), using the facility on a short-term basis to test and evaluate new technologies before they risk buying them, and licensing MODIL-sponsored inventions.

Right *An ion beam milling machine at the BMDO Optics MODIL. Ion beam figuring allows opticians to make lenses and mirrors with greater precision and fewer worker-hours than conventional optical finishing techniques. Because they can test emerging manufacturing technologies such as this one, MODIL participants can evaluate the technologies' capabilities at a neutral site before investing huge sums of money in them.*



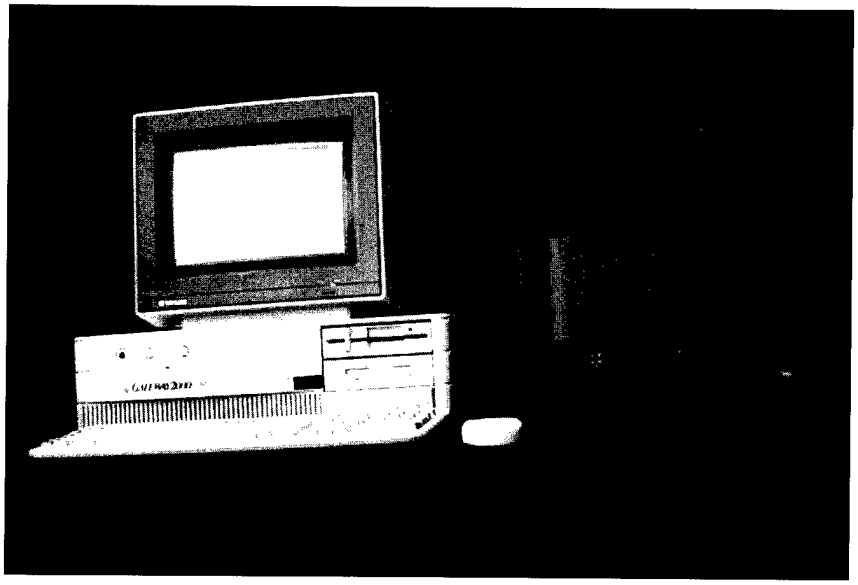
MODIL to reduce the time and cost of manufacturing beryllium optics. This research should speed manufacturing of beryllium optics 10 times and cut the cost threefold, making beryllium optics almost as easy to manufacture as aluminum optics.

■ ***High-Accuracy Natural Diamond Tooling Evaluation.*** In this CRADA, Contour Fine Tooling, Inc. is working at the Optics MODIL's PVTB to evaluate new high-accuracy natural diamond tools. Contour used the MODIL's diamond-turned machine equipment, which is some of the most accurate in the United States, to produce tools with less than 127 nanometer roundness error over 95 degrees of arc. Tools validated through this CRADA make the diamond-turning process more reliable and increase the quality of optics being manufactured. Contour plans to sell tools using this process in the commercial sector.

World's Fastest Scatterometer Installed at Optics MODIL

One of the MODILs' most important roles is to help move innovations from research prototype to the manufacturing floor. By giving innovators a place to demonstrate new technology with minimal risk to themselves and future users, the MODIL can spur widespread use of new technologies. For example, in March 1993, Breault Research Organization (BRO), Inc. (Tucson, AZ) installed the fastest and most powerful scatterometer available in the optics industry at the MODIL's Productivity and Validation Test Bed (PVTB). The PVTB allows industrial users to gain experience using technologies like this scatterometer, now on the market under the trade name OMNISCATR™, without investing huge sums of capital.

Because OMNISCATR™ is faster, more compact, less expensive, and more reliable than previously available scatterometers, it could expand scatterometer use from optics characterization to higher volume applications.These applications include assembly line testing, semiconductor fabrication and testing, and fiber optics quality control. OMNISCATR™ also could analyze the light output of light emitting diodes and liquid crystal displays, and monitor the contami-nation of clean rooms. BRO is currently concentrating on markets in nondestructive testing, aerospace, biomedicine, and the environment.



Above *Breault Research Organization's OMNISCATR™. Because OMNISCATR™ is faster, more compact, and more reliable that previously available scatterometers, it could expand scatterometer use from optics characterization to higher volume applications.*

OMNISCATR™ Benefits

Previously, scatterometer users had to compromise between cost, power, speed and size. OMNISCATR™, though, is a small, low-cost device that can collect and process 100 times more data than any scatterometer on the market in less than 1 second. This powerful new instrument acquires hemispherical scatter data, thereby allowing high-density complex scatter and speckle patterns to be seen in 3-D and near real time.

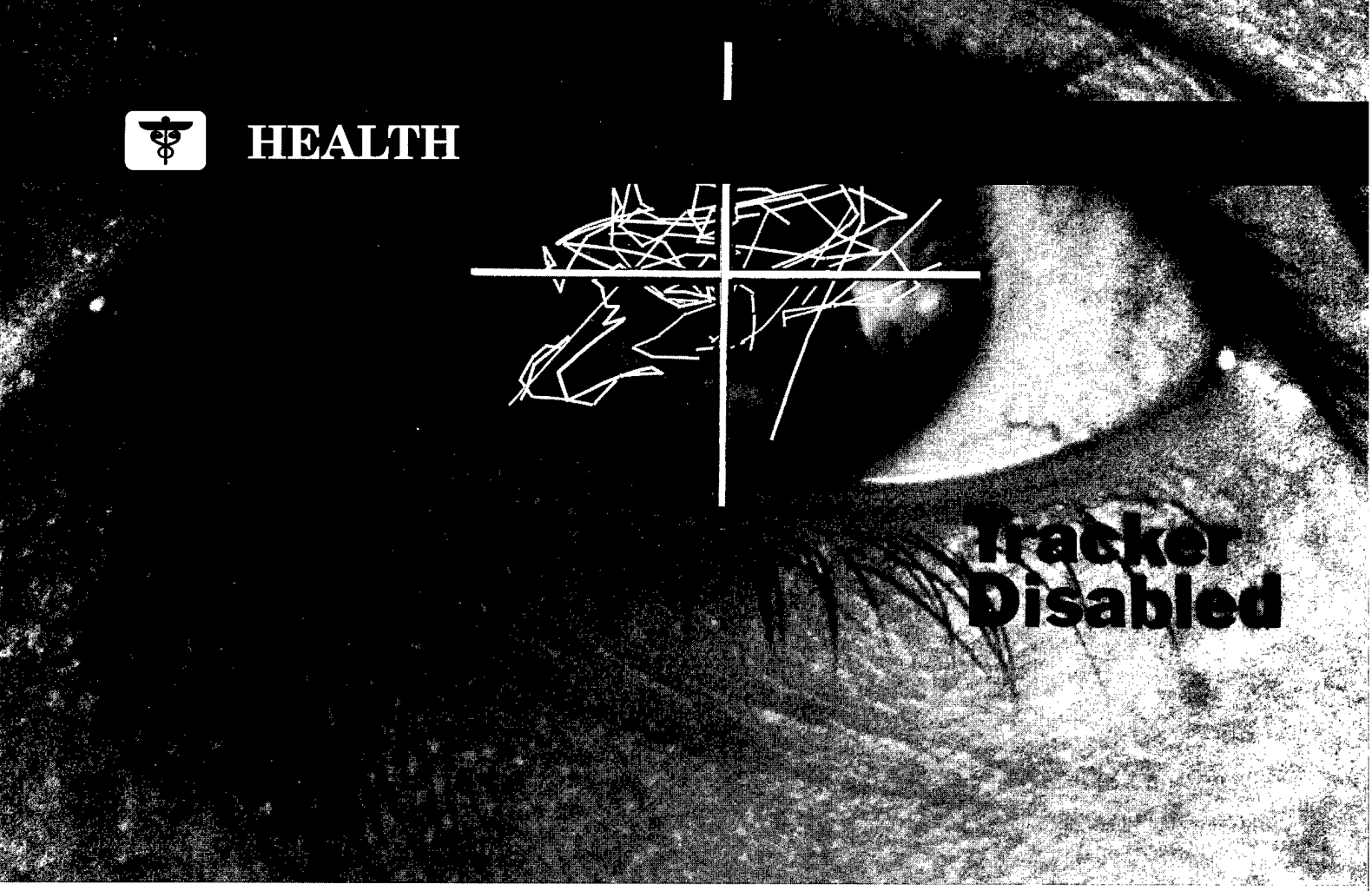
OMNISCATR™ advances scatterometer state of the art with four developments:

- ***Collection Optics.*** BRO's proprietary collection optics allow OMNISCATR™ to measure scattered light over a full 3-D segment of a hemisphere at high speeds and with high resolution; current systems can only collect a few simultaneous points, not a full hemisphere.

- ***High-Speed Detection Mechanism.*** With this mechanism, OMNISCATR™ can collect over 200,000 data points in less than 1 second; other systems can only collect a few points over 2 or 3 seconds.

- ***High-Speed Data Processing.*** BRO has developed software algorithms for OMNISCATR™ that can integrate 200,000 points of scattered light data in less than 1 second. When coupled with a high-speed data processor, OMNISCATR™ can process and display in-plane and hemispherical data in near real time. Current systems require a few seconds to process data.

- ***Laser Diode Technology.*** The OMNISCATR™ uses solid-state laser diodes, which make the system more rugged and compact (less than 1 cubic foot versus 120 cubic feet) than other systems.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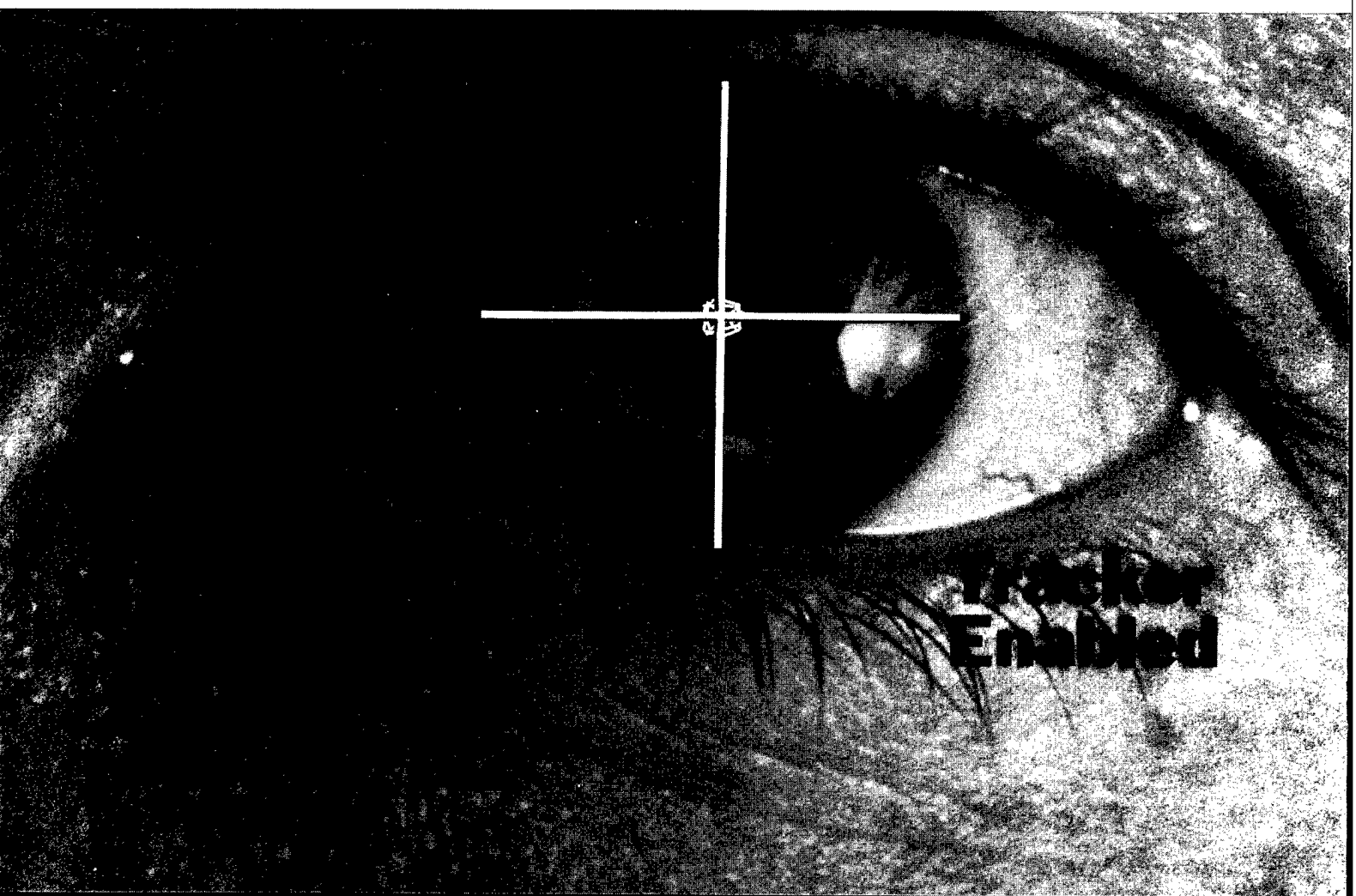
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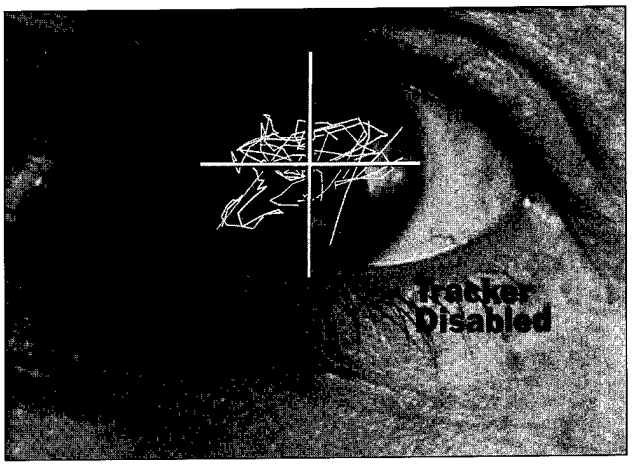

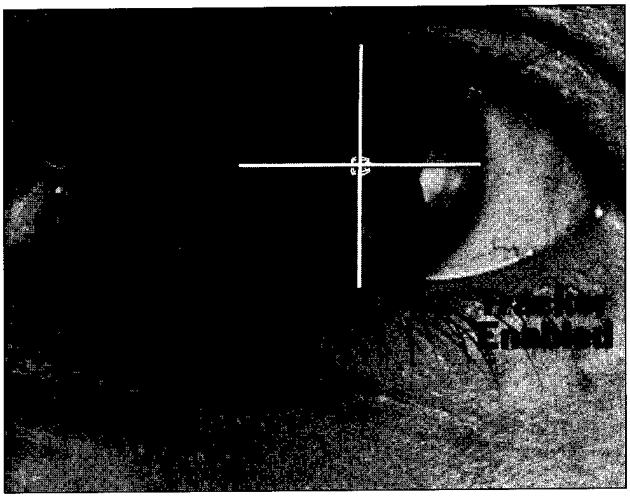

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Consider, for a moment, what BMD systems must do. First, the system must detect a ballistic missile in a cluttered background of clouds, earth, and decoys. Then, the system must track the missile, direct an interceptor at the target, and destroy it. Now consider what doctors must do to remove a tumor. First, doctors must detect the tumor in a sea of healthy tissue. Then, they must precisely determine the location and size of the tumor, and remove it without harming healthy tissue.

Despite these similarities, the transition from missile targeting to the operating room takes hard work. Many groups, though, have worked out the details and are now using BMD technology for imaging, cancer therapy, and other surgical procedures. Still more are currently working out the details with the hope of helping us live longer, healthier lives.

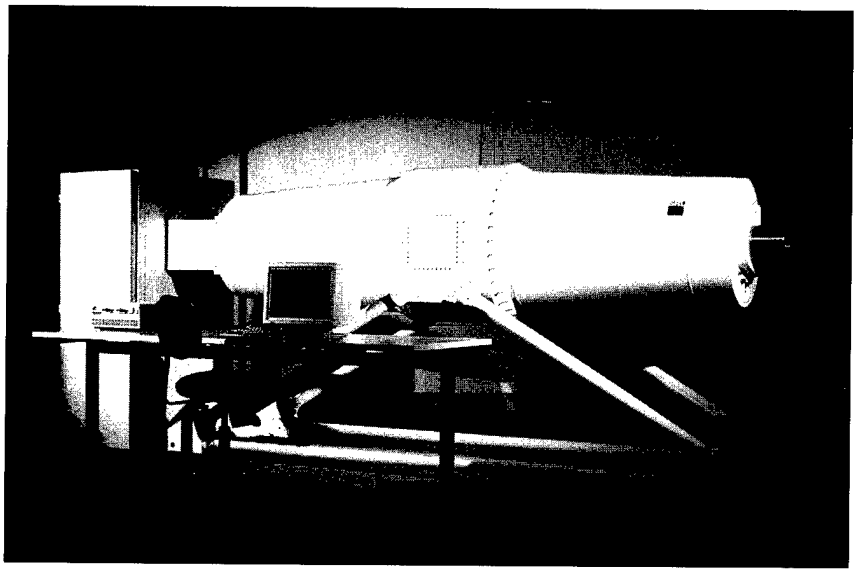
Technology to Watch

BMD Accelerator Installed at Renowned Medical Imaging Center

In May 1993, Science Research Laboratory, or SRL (Somerville, MA), installed a radioisotope delivery system at one of the foremost positron emission tomography (PET) imaging centers in the world, the new Neuroimaging Research Center at the Washington University School of Medicine (St. Louis, MO). The heart of SRL's PET radioisotope delivery system is the Tandem Cascade Accelerator (TCA), which is based on electrostatic accelerator technology developed for BMDO. The TCA can provide ion beam currents up to 10 times higher than conventional Van de Graaf accelerators.

SRL's delivery system will provide all PET radioisotopes for the center, thereby giving SRL a high-visibility site to demonstrate its system to the medical community. SRL also has had discussions with 15 organizations interested in commercializing PET imaging systems and is now receiving inquiries from potential customers for its PET systems.

In addition to the TCA, SRL has built two other working accelerators as the result of BMDO-sponsored research. SRL is pursuing other medical uses for these accelerators, such as boron neutron capture therapy, a method of removing deep-seated brain tumors, and imaging techniques used in coronary angioplasty and nutritional assessment. SRL also is developing a drug detection system for the Department of Commerce and plans to use the accelerators for explosives detection and cargo container interrogation. In 1989, SRL formed a new company, Accelerator Applications, Inc. to bring this accelerator technology to medical and industrial markets.



Above *Science Research Laboratory's Tandem Cascade Accelerator, or TCA. Recently installed at Washington University's Neuroimaging Research Center, the TCA could provide all the radioisotopes needed for positron emission tomography (PET) imaging at the Center. Clinical use of PET imaging–proven to be an important diagnostic tool in cardiology, neurology, and oncology–has been severely limited by the high cost of producing radioisotopes. The TCA promises to help end this limitation.*

Accelerator Advances Needed to Spur Clinical Use of PET

PET maps important regions of cellular activity within the human body by introducing and following a quickly decaying radioisotope tracer. Because no other imaging technique maps organic chemical activity, clinical PET imaging would give doctors an important diagnosis tool in cardiology, neurology, and oncology.

Widespread clinical use, though, has not yet occurred because it takes large, high-power cyclotrons to produce radioisotopes. While appropriate for research, cyclotrons are extremely expensive for widespread clinical use. Cyclotrons' high cost means clinical use of PET depends either on a regional distribution center or smaller, lighter accelerators.

Regional distribution centers have limited potential, since most radioisotopes have short half-lives (sometimes only minutes). With such short half-lives, the centers cannot transport radioisotopes long distances before they lose their effectiveness. Smaller, lighter accelerators, therefore, must be developed to introduce widespread clinical use of PET. These accelerators must produce the four most common radioisotopes—fluorine 18, nitrogen 13, oxygen 15, and carbon 11. But to get adequate quantities of these radioisotopes when using low-power levels, the accelerators must produce high-current beams. Accelerators developed for the BMD Neutral Particle Beam (NPB) program meet these requirements.

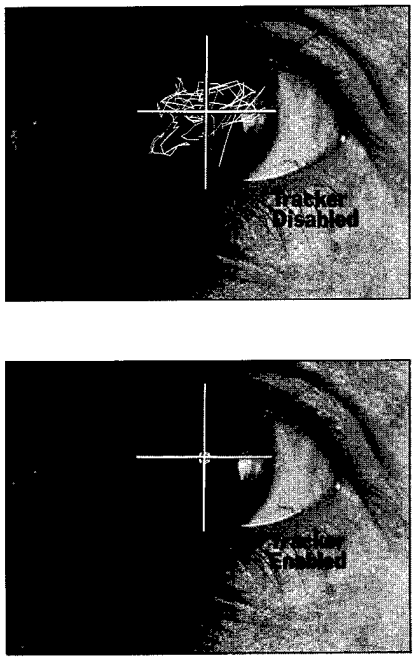
Because NPB accelerators could propel PET imaging from the lab to the hospital, BMDO started the miniaturized PET accelerator program in 1989. Through this program, BMDO funded development of SRL's Tandem Cascade Accelerator.

T-PRK™ Eye Tracking to Improve Vision Surgery

For millions of people who must wear glasses, laser surgery may someday be able to permanently correct vision by changing the shape of the eye's cornea. But one problem limits the surgical effectiveness: the eye won't keep still. No matter how hard we try, our eyes make small, rapid jumps in fixation from point to point. Without the ability to track and compensate for this involuntary motion, known as saccadic eye movement, lasers can't properly change the shape of the cornea. This inability leads to uncorrected vision and, in extreme cases, damage to healthy tissue.

In response to this need, Autonomous Technologies Corporation (Orlando, FL) has adapted object detection and ranging technology originally developed for missile targeting and space docking systems to track irregular eye movements. With this technology, Autonomous Technologies is developing a new medical laser product that performs tracker-assisted photorefractive keratectomy (T-PRK™). T-PRK™ uses a laser to change the optical focusing properties of the eye by modifying the shape of the outer layer of eye tissue.

In 1993, Autonomous received private investor funding to develop its T-PRK™ Alpha Unit as a direct result of a prototype tracker developed under a BMDO SBIR Phase II project. The T-PRK™ unit will also incorporate laser radar (LADAR) technology that Autonomous developed in earlier BMDO and NASA SBIR projects.



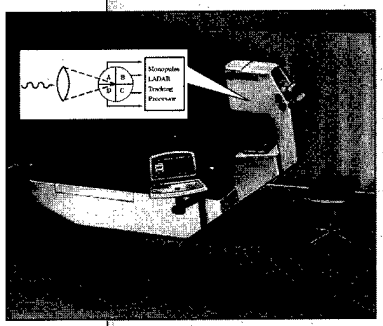
Left A comparison of a laser's ability to change the optical focusing properties of the eye by modifying the shape of the outer layer of eye tissue. In the upper picture, AutonomousTechnologies' LADARVision™ eye tracker is not operating, resulting in a high degree of eye movement error (shown in white). In the lower picture, the tracker allows the laser to remain perfectly centered, despite the rapid motion of the eye.

Eye Tracking With Laser Radar

Autonomous Technologies has extended monopulse radar tracking techniques to the optical domain for fast, precise tracking. In ballistic missile defense, optical and infrared LADAR offers dramatic improvements in tracking accuracy, clutter rejection, and countermeasure resistance over its microwave radar counterpart.

This work has resulted in a heterodyne Doppler LADAR that provides monopulse tracking using advanced digital recovery techniques. With certain proprietary advances and simplifications, Autonomous has now applied this technology to rapid, low-cost eye tracking, while retaining the following benefits:

- High error signal data rate for wide bandwidth tracking
- High clutter rejection from ablated debris
- Isolation from false target fluctuations
- Unique antenna beamforming for high tracking accuracy.



***Above** An artist's concept of Autonomous Technologies' T-PRK™ Alpha Unit, which could permanently correct a patient's vision by changing the shape of the eye's cornea with a laser.*

Photodynamic Therapy Can Destroy Viruses in Blood Supply

Technique Also Could Treat Cancer and AIDS Patients

Baylor Research Institute (Dallas, TX) researchers have developed photodynamic therapy techniques in which light-sensitive dyes kill viruses or cancers when irradiated with laser light. Funding for the laser research came from BMDO's Medical Free Electron Laser program, which Congress established to transfer BMDO-sponsored free-electron laser technology to medical and other spinoff applications.

In photodynamic therapy, photoactive dyes selectively attach to an enveloped virus. When light of a specific wavelength and sufficient intensity shines on the dye, a chemical reaction begins that gives off a toxic oxygen radical for a short distance and for a fraction of a second. The oxygen radical breaks down the viral sheath and kills the virus. Because dyes only produce this oxygen radical when they absorb laser light of a specific wavelength, the Baylor team used a free-electron laser and other lasers to deliver the correct wavelength.

Because nondyed tissue can interfere with photodynamic processes, the first application to result from this research was a method to purify donor blood bank supplies. In a more exciting recent discovery, Baylor found a dye that can be preactivated; that is, after laser irradiation the dye retains its antiviral properties until it comes into contact with enveloped viruses in the blood stream. This discovery means the dye can be irradiated before it is injected into blood, making possible a drug-like treatment for AIDS and similar viral infections.

Baylor has licensed each technique to industry. The photoactive dye used for blood purification has passed toxicology testing, but has yet to receive approval from the Food and Drug Administration (FDA). The FDA also recently approved the preactivation method for clinical trials.

Another Application: Tissue Welding

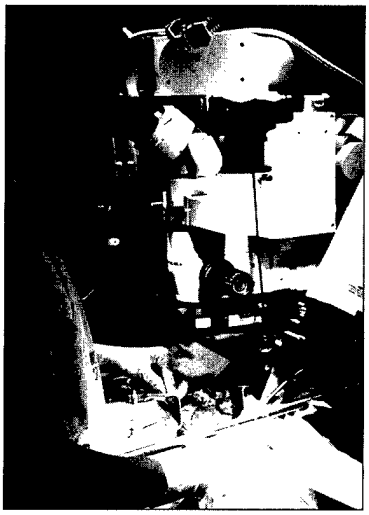
Baylor also uses photodynamic technology to bond biological tissues with repetitively pulsed laser beams. Dye droplets introduced at the interface between two tissue layers absorb the pulsed laser light, while the surrounding tissue does not. As a result, the tissue layers treated with the dye become thermally fused without damage to surrounding tissue.

The tissue welding process applies best to collagen-rich cellular structures and looks particularly promising for blood vessels and nerve tissue. A microjet device coupled with a pulsed laser source is being developed to deliver dye and irradiation to the tissue site with high precision. To commercialize this process, Baylor is working with two companies to produce clinical tissue welding devices.

Right *A Baylor Research Institute researcher demonstrating tissue welding using photoactive dyes. Baylor is currently working with two companies to commercialize clinical tissue welding devices.*

Collaborative Research Yields New Ideas

In the course of investigating dyes for medical applications, Baylor researchers discovered a photoactive dye that can be used to monitor corrosive wear in mechanical systems. When irradiated with light, this dye emits one wavelength of light when it binds to paramagnetic metal ions, the by-product of corrosive wear, and another wavelength of light when no ions are present. Currently, no other method can distinguish between the by-products of corrosive wear (metal ions) and frictional wear (metal molecules). As a result, this method could improve maintenance of mechanical systems by helping engineers determine when oil needs to be replaced and when it just needs chemical additives to stop corrosion. This interaction between biological, materials, and physical scientists exemplifies how mixing specialties in a research program can produce unexpected payoffs.

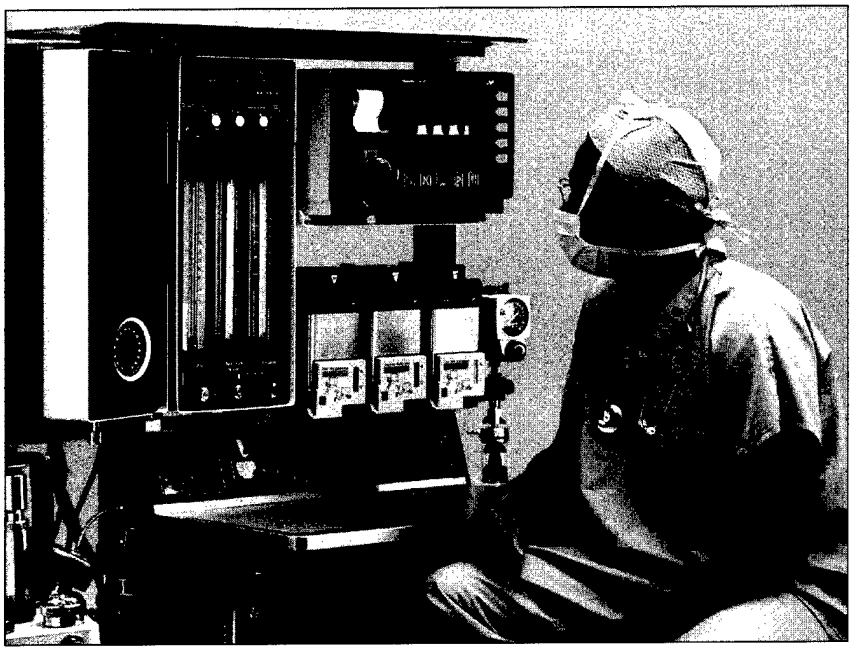


Accurate Anesthesia Monitoring Saves Lives

A spinoff company from the University of Utah recently won a 1993 *R&D 100* Award for Rascal® II, a device that monitors patient respiration during surgery, as one of the 100 best new products of the year. The respiration monitor attaches to an anesthesia machine to detect how much oxygen, nitrogen, carbon dioxide, and anesthesia a patient inhales and exhales. By providing immediate feedback, Rascal® alerts anesthesiologists to potential dangers at the earliest possible moment.

Funding from BMDO's Medical Free Electron Laser program at the University of Utah helped Biomaterials International (Salt Lake City, UT) validate several optical designs of a Raman spectroscopy gas analyzer (see sidebar). This validation allowed the company to build a prototype analyzer and begin commercial testing of the device.

Biomaterials International, which changed its name to Ohmeda after BOC Health Care, Inc. bought the company in 1990, owns several patents covering the Raman gas analysis system in Rascal®. Ohmeda also has exclusive rights to several other patents assigned to the University of Utah.

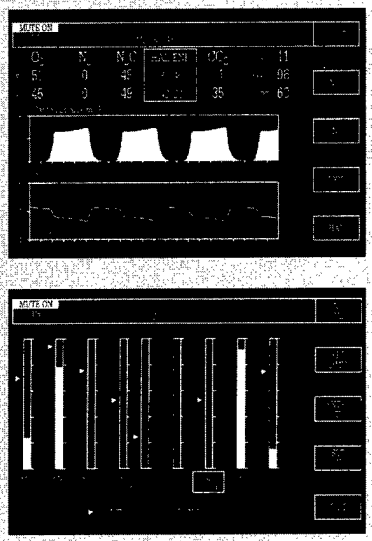


Above *Ohmeda's Rascal® II respiration monitor. This monitor attaches to an anesthesia machine to detect how much oxygen, nitrogen, carbon dioxide, and anesthesia a patient inhales and exhales. Funding from BMDO Medical Free Electron Laser Program helped researchers validate several optical devices of this Raman spectroscopy gas analyzer before they built a prototype and began commercial testing.*

Raman Spectroscopy The Heart of Rascal® II

Raman spectroscopy can detect a substance's unique chemical composition by shining laser light on a sample of the substance. In the technique, laser light excites the vibrational and rotational modes of a molecule to a higher energy level upon hitting the molecule. As the molecule loses this energy, it re-emits scattered light at a longer wavelength than that of the original laser beam. Because the change in wavelength is different for each molecule, this technique can measure the chemical composition of various samples.

This principle led laser researchers at the University of Utah to conceive a system that allows anesthesiologists to monitor the respiratory gas of patients during surgery. Soon after, these researchers formed Biomaterials International to bring their idea to the operating room.

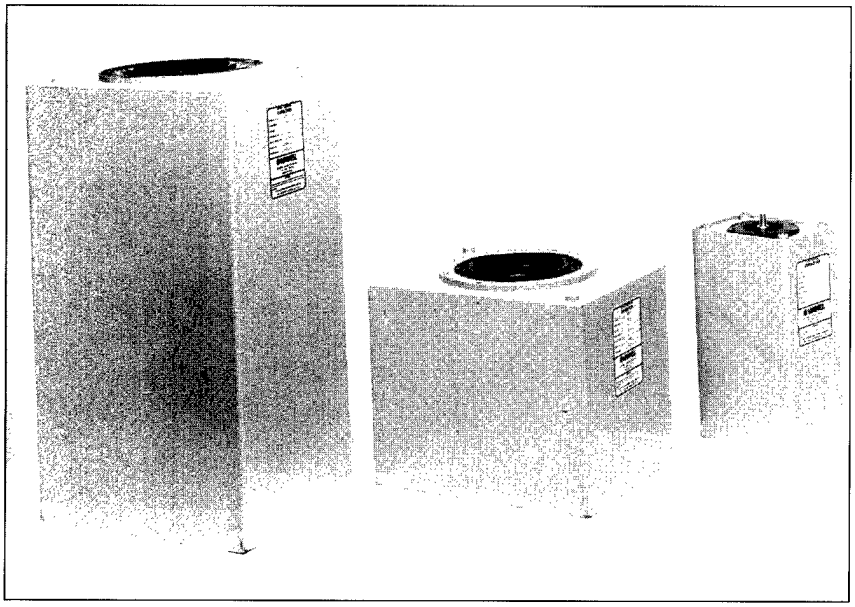


Top and Bottom *Rascal®'s output screens. By providing immediate feedback about a patient's respiration, the monitor alerts anesthesiologists to potential dangers at the earliest possible moment.*

Heart Defibrillators Powered by BMD Capacitors

To get the heart pumping again after a heart seizure, cardiac defibrillators need small, lightweight capacitors that can send large jolts of electricity to the heart. BMDO needs similar capacitors to power accelerators and lasers. This similarity has led to a new business outlet for Maxwell Laboratories, Inc. (San Diego, CA), which has supplied over 30,000 high energy density capacitors for use in cardiac defibrillators. BMDO supported the development of these capacitors starting in the mid-1980s.

Maxwell has also supplied over one thousand 50-kilojoule capacitors for large capacitor banks used in electric gun and fusion research. The capacitors have further commercial potential for aircraft strobe lights and deicers, mobile rock crushers, and underground tunneling machines. Spinoff military applications include tactical electric guns, electromagnetic active armor, active sonar, and mine field clearing. Maxwell is also developing new designs of the high energy density film capacitors with a larger voltage range, faster discharge rate, and faster repetition rate that will provide them with new uses.



Above *Maxwell Laboratories' high-voltage, pulse-discharge capacitors, whose development BMDO supported starting in the mid-1980s. Maxwell has sold these capacitors for use in cardiac defibrillators, electric gun research, and fusion research. Other commercial uses could occur in aircraft strobe lights and deicers, mobile rock crushers, and underground tunneling machines.*

Film Capacitor Design

Capacitors accumulate electrical charge and energy on the surfaces of conducting plates that are insulated from each other by a dielectric material. The amount of charge or energy per unit volume can be increased by:

- Employing insulating materials with a higher dielectric constant
- Reducing the thickness of the insulating material
- Increasing the voltage between the conductors, and thereby increasing the electric field in the dielectric material
- Reducing the thickness of the conducting plates and the volume of the packaging.

Through a combination of these four approaches, Maxwell developed high-voltage, pulse-discharge capacitors with energy densities as high as 4 joules per cubic centimeter for BMDO. These high energy density capacitors have a lifetime of about 1,000 pulses, low repetition rate capability, and a 250 kilojoule storage capacity (for capacitors in an 87-liter package that operate at a voltage of 7.5 kilovolt). With energy densities up to 3 joules per cubic centimeter, Maxwell's commercially available capacitors can store energies of over 50 kilojoules.

Gamma Ray Detectors Provide Clearer View of the Heart

Above *Positron emission tomography image taken using gamma ray detectors developed at the University of Texas at Dallas, or UTD, and the University of California at Los Angeles. UTD is now working with the University of Texas Southwestern Medical Center at Dallas to apply this technology to medical imaging. Depending on the size of the scintillating fibers used to detect gamma rays, UTD's detectors could have about 10 times more resolving power than other detectors.*

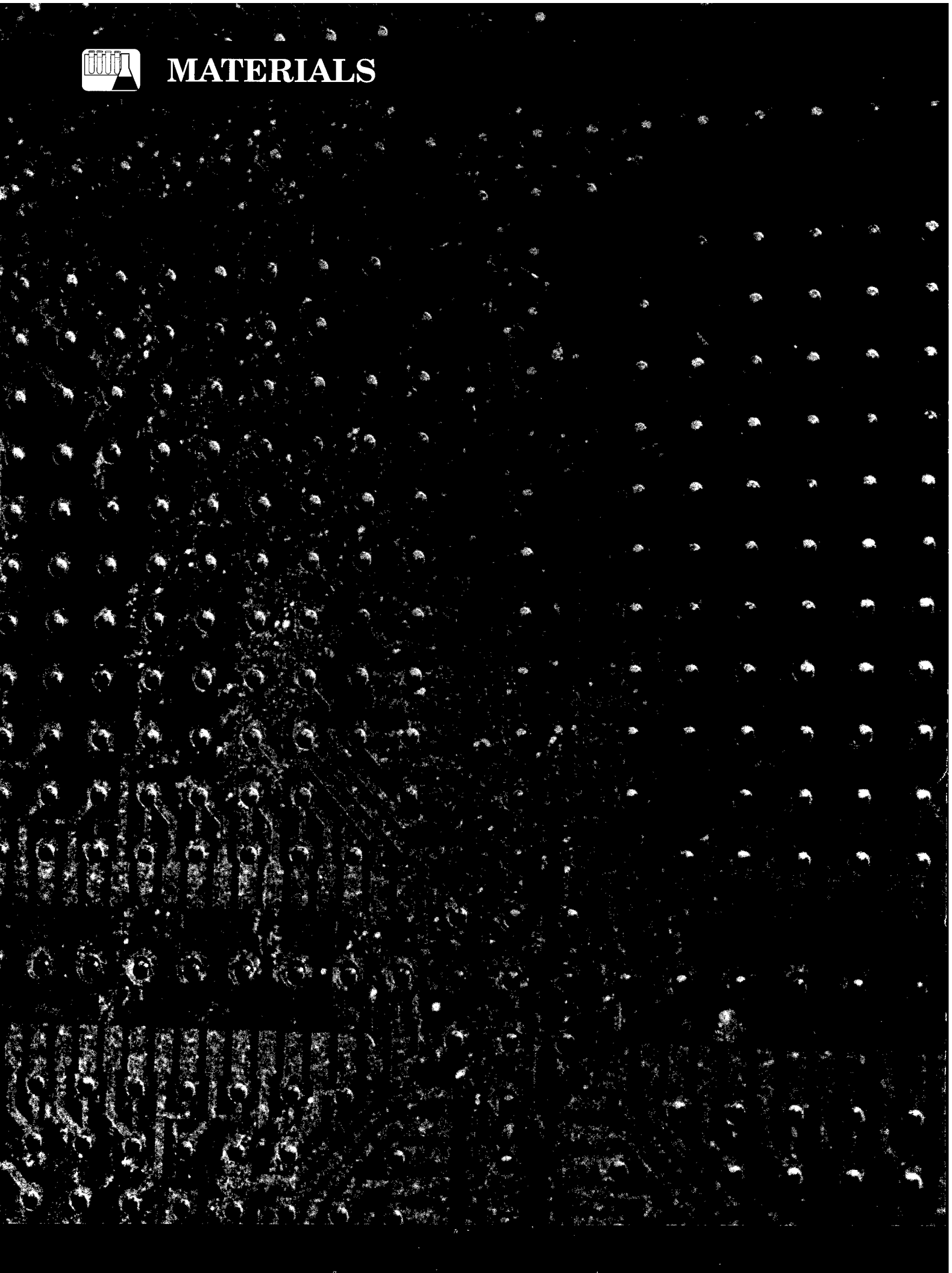
In two important new imaging techniques, single photon emission computer tomography (SPECT) and positron emission tomography (PET), doctors can view organs and the chemical processes in them by detecting gamma radiation emitted from a radioactive isotope. As a result, improved gamma ray detectors from the University of Texas at Dallas (UTD) can increase the resolving power of SPECT and PET imaging about tenfold.

UTD developed this detector technology in a joint project with the University of California at Los Angeles to build a space-based gamma ray telescope for BMDO. UTD researchers are now working with the University of Texas Southwestern Medical Center at Dallas to apply this technology to medical imaging. At the end of this research, which is funded by the State of Texas, the team plans to build a prototype clinical-size PET/SPECT camera. This camera will be used in a joint industry-university project to build a full-scale commercial imaging system. Once the detector technology is developed, the group also plans to use it in miniaturized endoscopic probes or imagers.

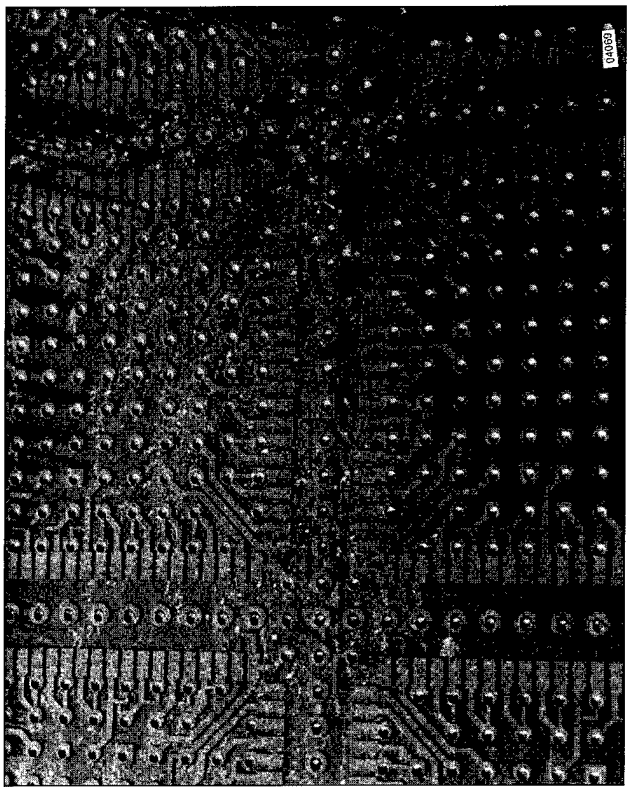
Plastic Scintillating Fibers Provide Imaging Edge

UTD researchers employ plastic scintillating fibers and position-sensitive photomultipliers to increase the efficiency of a gamma ray detector used in medical imaging. Their detector begins operating when gamma rays strike a detector array made of scintillating fibers. When the gamma ray photons hit the fibers, the detector emits electrons through Compton scattering or the photoelectric effect. These electrons then pass through the fibers, raising atoms in the scintillating fiber to a higher energy state. When the atoms return to the ground state, they emit light. Position-sensitive photomultipliers can detect this light and convert it into an electrical signal. A computer, in turn, can reconstruct an image of the gamma ray emitter from the electrical signal.

The scintillators developed at UTD are made of polystyrene fibers that increase detector resolution and efficiency; these increases result in detectors with excellent spatial resolution (less than 1 mm) and time resolution (less than 10 nanoseconds). As a result, SPECT and PET imaging increase their resolving power about tenfold, depending on the fiber size, while improved time resolution will minimize background noise and accidental readings.



MATERIALS



Foster-Miller, Incorporated - Page 65

One of the most certain ways to make something work better—whether it's a missile interceptor, a bicycle, or an electronic gadget—is to make it out of a stronger, lighter, or better insulating material. If it makes a missile interceptor stronger, it also makes a bicycle stronger. As a result, BMDO-sponsored materials research can have far-reaching impact. In one case, artificial diamond coatings, the beneficial properties can improve so many products—semiconductors, machine tools, heat sinks, optics, and a host of others—that its impact on the economy could be immeasurable.

New Venture Targets Diamond Films in Industrial Markets

Laboratory researchers have long sought to harness diamond's extraordinary properties by developing new methods of coating surfaces with diamond thin films. Today, their drive is beginning to pay off, as commercial developers of coated optics, machine tools, electronic packages, and display devices are starting to take advantage of this research. The BMDO IS&T program's diamond technology initiative, which included a project at the Research Triangle Institute, or RTI (Research Triangle Park, NC), has helped spur this new-found enthusiasm in the commercial world.

The reason for commercial developers' earlier hesitancy stems from simple economics. Diamond costs hundreds of dollars a carat, too much for all but the most esoteric applications. But if initial tests are any indication, RTI's concept may reduce the cost of diamond enough to eliminate this barrier. With the support of the BMDO IS&T program, RTI has developed a method for producing large-area diamond films using low-cost, energy-efficient equipment. So far, RTI has used the equipment to coat coupons as large as 20 square inches.

In a critical step toward commercialization, 3M Company (St. Paul, MN) has teamed with RTI to refine the process and scale it to production requirements. 3M provided financial and technical support to allow the recent construction of a manufacturing prototype scale reactor that could coat coupons as large as 200 square inches. The Advanced Research Projects Agency also helped fund this scale-up effort.

The teaming of 3M and RTI represents a major milestone in the development of diamond technology in the United States. According to RTI's Robert Markunas, "Our research benefited from collaborations fostered by BMDO's IS&T Program with universities, such as Penn State University, and government research institutions, such as the Naval Research Laboratory. Now that same cooperative approach is being extended to an industrial collaborator with many potential product applications and an excellent track record implementing new technologies."

Above *An optical micrograph of a diamond coating made at Research Triangle Institute (RTI). Using low-cost, energy-efficient equipment developed with the support of the BMDO IS&T program, RTI has coated coupons as large as 20 square inches. To refine its process and scale it to product requirements, RTI recently teamed with 3M Company.*

Diamond Property Benefits

- ***Hardness.***
Diamond has a hardness of 9,000 kilograms per square millimeter, two times harder than its nearest competitor, boron carbide. This hardness makes diamond an excellent coating for machine tools or other areas where wear protection is important.

- ***Coefficient of Friction.***
With a coefficient of friction of 0.05 to 0.1, diamond's "slipperiness" equals or betters Teflon®'s. Combined with its hardness, diamond makes an ideal coating for bearings, extruders, dies and cookware.

- ***Tensile Strength.***
Diamond fibers can withstand stretching forces of 290 kilograms per square millimeter, nearly 10 times better than alumina. This strength makes diamond a good candidate for reinforced composites.

- ***Electrical Resistivity.***
Diamond, with a resistivity of 1×10^{16}, insulates against electricity 10 times better than alumina. This resistivity, combined with its high thermal conductivity, makes diamond an ideal electronic heat sink.

- ***Thermal Conductivity.***
For every degree Kelvin, diamond can conduct 2,000 watts of heat per meter, nearly five times better than silver.

- ***Thermal Shock.***
Diamond can withstand thermal stresses of 10 million watts per meter, 1,000 times better than Zerodur®.

- ***Optical Transmission.***
Diamond can transmit light with wavelengths from 0.22 to over 100 micrometers, compared to 0.2 to 4 micrometers for silica. This transmission range, combined with a hardness that will prevent damage to the optic, makes diamond an ideal optical coating.

Polymers for Building Airplanes, Packaging Food

Start-up Company

Foster-Miller, Inc. (Waltham, MA) has developed ways to make a new class of materials used for anything from aircraft structures to food packaging. Developed through BMDO and Air Force SBIR contracts, these ordered polymers have such broad potential that Foster-Miller has formed a subsidiary company, Superex Polymer, Inc., to commercialize them.

Superex Polymer expects to enter strategic alliances with other companies to manufacture and sell products based on the technology. To date, eight companies have invested $1.3 million in ordered polymer R&D at Foster-Miller and Superex, three companies have licensed or have options to license processing technology, and three more companies are negotiating licenses.

Some uses of ordered polymers that Foster-Miller is now exploring include:

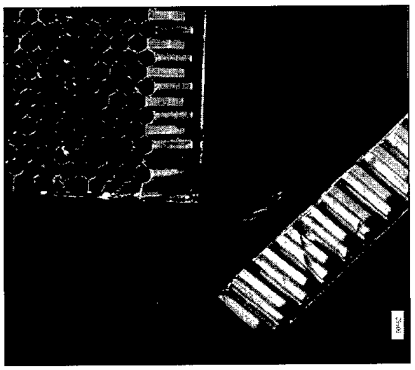
- *Food Packaging.*
Packaging materials stop oxygen and water vapor from passing through them; otherwise, food may spoil, pharmaceuticals may degrade, and dangerous chemicals may pass into the atmosphere. Ordered polymers are about 100 times less permeable to oxygen and water vapor than commonly used polymer packaging materials. As a result, ordered polymer-based packages can provide the high barrier properties of aluminum foil in a microwavable container.

- *Electronics Packaging.*
Because ordered polymers have a low dielectric constant, they can increase interconnection density in printed circuit boards by a factor of 10 over current technology.

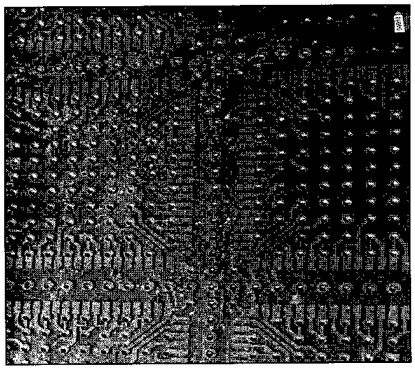
- *Aircraft and Satellite Structures.*
An ordered polymer honeycomb core should be one-half to one-third the weight of polyaramid or aluminum cores of equivalent stiffness. As a result, they are ideal for high temperature stability, low coefficient of thermal expansion, and corrosion-free applications.

- *High Energy Density Capacitors.*
Ordered polymers have a fibrous network that increases the surface area in which electrical charge can be stored. As a result, this technology will reduce the size and increase the reliability of high energy density capacitors.

- *Cryogenic Storage.*
Low permeability thin-film liners provide up to 90 percent weight savings over aluminum liners. When used as insulating components and cryogen feed lines, ordered polymers reduce thermal losses through tank fittings and feed lines by over 90 percent.



Above *Honeycomb cores made of Foster-Miller's ordered polymers. These cores should be one-half to one-third the weight of aluminum cores of equivalent stiffness.*



Above *A printed circuit board made of Foster-Miller's ordered polymers. Ordered polymers can increase interconnection density in these boards to 10 times that of today's circuit boards.*

Ordered Polymers Provide Built-In Fiber Reinforcement

Ordered polymers have long stiff molecules that, when processed correctly, form a self-reinforced microstructure of fibrils. This microstructure is analogous to continuous fiber reinforcement, where fibers or fabrics form a matrix that gives a material extra strength and stiffness. The key difference is that the microstructure is inherent to an ordered polymer (a fiber matrix does not need to be added), and the fibrils are 100 to 1,000 times finer than fibers used in continuous fiber reinforcement.

As a result of their molecular structure, ordered polymers have many favorable mechanical properties, such as a specific strength and modulus (stiffness) twice that of aluminum. Other properties include:

- Low coefficient of thermal expansion
- Low thermal conductivity
- Excellent gas barrier properties
- Low dielectric constant
- High dielectric strength
- Radiation hardness.

Different processing techniques allow researchers to precisely control the polymer's strength, stiffness, and coefficient of thermal expansion. In addition, the self-reinforcing fibrils do not experience the microcracking found in fiber composites, and are much thinner (less than 0.05 mm) than fiber composites.

Deals

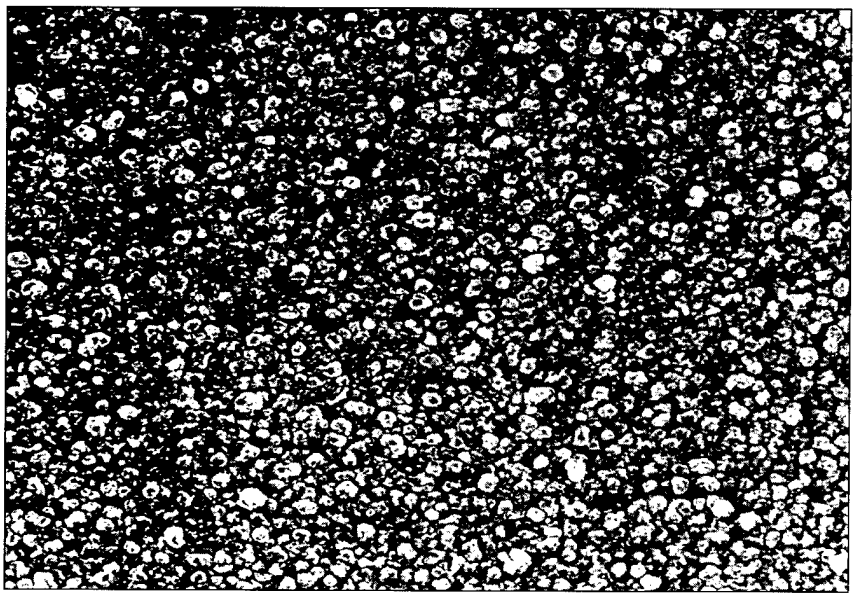
Amorphic Diamond™ Coatings On Verge of Commercial Breakthrough

SI Diamond Technology, Inc. (Houston, TX) recently completed an initial public offering of 1 million shares of stock that raised nearly $5 million. The company plans to use this money to finance new diamond thin-film products, the first of which will be a commercial system for applying Amorphic Diamond™ Coatings (ADCs).

SI Diamond licensed ADC technology from The Center for Quantum Electronics at the University of Texas at Dallas (UTD), which developed the method for producing ADCs with BMDO IS&T program funding.

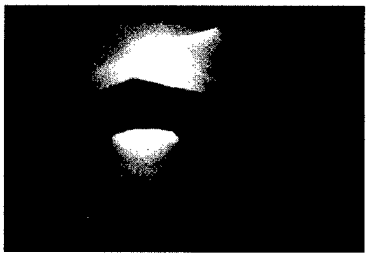
SI Diamond initially plans to offer diamond-coating services for original equipment manufacturers that wish to out-source their coating requirements. Niche markets that the company plans to pursue include diamond-coated surgical tools, dental instruments, mechanical bearings, electronic components, and other small, high-value items. In the long term, SI Diamond plans to offer a full line of diamond-coating equipment suitable for a variety of industries.

In addition to SI Diamond's commercialization efforts, UTD has pursued further applications in a grant from the State of Texas to coat floppy disks with a protective diamond coating. To increase packing densities, computer makers must move the head closer to the hard disk. Unfortunately, closer contact between the computer head and the disk causes more bit errors. ADCs can prevent these errors by protecting the disk. As a result, disks could store megabytes more information than is now possible. UTD plans to extend this technique to hard disks, and is pursuing collaborative arrangements with industry in this area and several others.



Above *An optical micrograph of an Amorphic Diamond™ Coating, developed at the University of Texas at Dallas while conducting research sponsored by the BMDO IS&T program. Because Amorphic Diamond™ has a hardness nearly equal to (and possibly better than) natural diamond, 1 to 3 micron-thick films of this coating can extend the lifetime of materials up to a thousandfold.*

Making Amorphic Diamond™ Coatings



Above *The laser ablation process used to make Amorphic Diamond™ Coatings.*

To make ADCs, a pulsed laser heats the graphite feedstock in a low pressure, ultrahigh vacuum system to create a carbon vapor. When the carbon vapor settles on the substrate, it creates a thin-film coating of Amorphic Diamond™. A planetary drive system ensures that only vapor hot enough to produce high-quality films settles on the substrate.

The resulting film consists of densely packed nodules of diamond crystals linked by a network of other carbons. They can have a diamond content as high as 85 percent and hardness nearly equal to or possibly better than natural diamond. Further, ADCs are less brittle than crystalline diamond, and bond better to the substrate because they have less internal stress. Low internal stress also allows the process to deposit films up to 5 microns thick.

Because the substrate remains at a relatively low temperature (about 35°C) during deposition, ADCs can be grown on almost any substrate, including silicon, titanium, gold, silver, aluminum, copper, stainless steel, and ceramics.

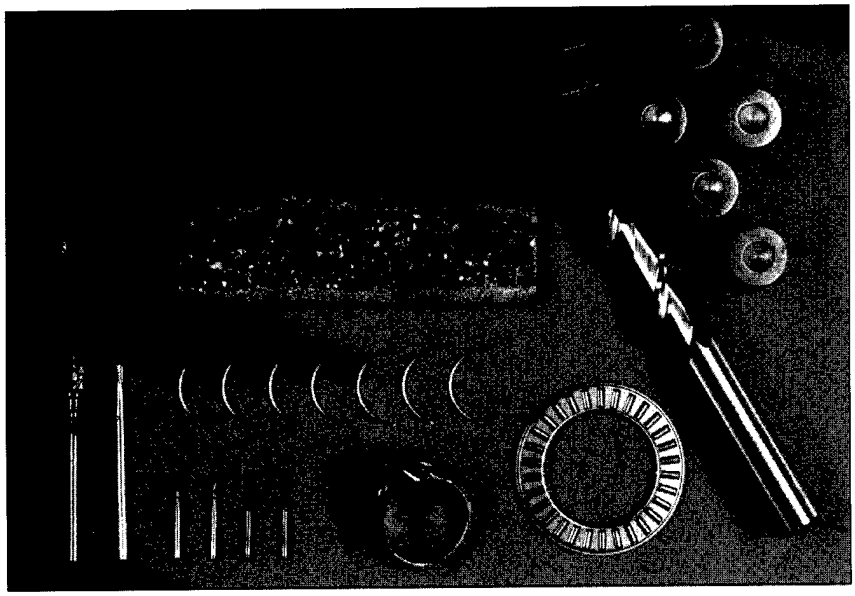
Diamond Thin Films Bring SI Diamond More Commercial Opportunities

In addition to SI Diamond Technology, Inc.'s work to commercialize Amorphic Diamond™ Coatings (see previous page), the company is developing—with the help of BMDO SBIR contracts—a range of diamond thin-film technologies with considerable commercial potential.

In one of the most promising projects, SI Diamond is participating in a joint technology demonstration project with the Microelectronics and Computer Technology Corporation (MCC), a research consortium of computer firms. In this project, SI Diamond developed a diamond cold cathode electron source in flat-panel display screens (see side bar).

In another BMDO SBIR project, SI Diamond is developing a diamond deposition process based on atomic layer epitaxy (ALE). Because ALE deposits synthetic diamond on a substrate a single atom layer at a time, this technique provides evenly and finely controlled rates of deposition. ALE may be used to grow single-crystal diamond of varying compositions. Furthermore, ALE deposits diamond at low temperatures, which eliminates the cracking common in high-temperature processes. This cracking occurs because the substrate shrinks more than the coating layer as they cool.

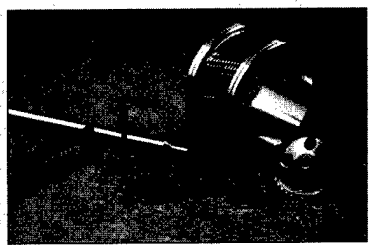
SI Diamond has also developed a fast atom doping process in which researchers shoot atoms at a diamond film as the film is grown using chemical vapor deposition. Fast atom doping thus adds the impurities necessary for the eventual manufacture of n-type semiconducting diamond. To date, no other technology can reliably dope diamond films without damaging the natural crystalline structure of the film. SI Diamond received a patent for this process in July 1993.



Diamond Cold Cathodes

Because most cold cathodes have poor stability, other technologies, such as active matrix liquid crystal displays (AMLCDs), have been considered better options for producing flat-panel displays. By increasing cathode stability, diamond coatings would allow cold cathodes to compete with other technologies. Diamond cold cathodes should provide the following advantages over competing technologies:

- Brightness comparable to cathode ray tube video displays
- Definition suitable for high-definition television
- Wide field of view
- Screen size of several feet (diagonal)
- Screen thickness under 1 inch
- Ease of manufacture greater than AMLCDs
- Low production costs.



Left and Above *Some of SI Diamond's diamond-coated products. SI Diamond, which recently completed an initial public offering of 1 million shares of stock, plans to offer diamond-coating services for original equipment manufacturers that wish to coat surgical tools, dental instruments, mechanical bearings, electronic components, and other small, high-value items. SI Diamond is also developing diamond cold cathodes used in flat panel display screens and a fast atom doping process that may allow the company to manufacture n-type semiconducting diamond.*

Award-Winning Sol-Gels: Materials of Substance

GELTECH, Inc.'s (Alachua, FL) patented "sol-gel" process has been widely recognized for its commercial potential. Because of the versatility and low cost of the sol-gel process, it has won an Advanced Technology Program (ATP) grant from the Department of Commerce, an R&D 100 Award from R&D Magazine, a Photonics Circle of Excellence Award from *Photonics Spectra* magazine, and a Commercial Technology Achievement Award from *Laser Focus World*. Sol-gel products on the market include a transparent, porous silica glass, high-purity silica powders, and custom-made dense silica optics.

GELTECH originally developed its sol-gel technology for the BMDO SBIR program to produce porous silicas that can replace sapphire in rocket windows. Because of a laundry list of beneficial properties, sol-gels have uses in areas ranging from biology to optics, as shown by the following charts:

POROUS SILICA GLASS

Properties	Applications
■ Mechanically strong and hard ■ Hydrophilic ■ Controlled pore size (from 25 to 200 ångströms in diameter) ■ Capillary action from pore structure ■ Ability to withstand high temperatures	■ Filters ■ Photoactive dye and polymer matrices ■ Chemical, biological, and optical sensors ■ Optical waveguides and arrays ■ Holography ■ Catalyst supports ■ Transpiration-cooled optics ■ Thermal insulation

SILICA POWDERS

Properties	Applications
■ Controlled density (from 1.7 to 2.2 g/cm^3) ■ Amorphous structure ■ More than 99.9 percent pure ■ Low dielectric constant ■ Refractive index of 1.42 to 1.46 ■ Low coefficient of thermal expansion	■ Polymer composites for electronics ■ Dental composites ■ Biomedical applications ■ Liquid crystal display spacers ■ Light diffusers

DENSE SILICA

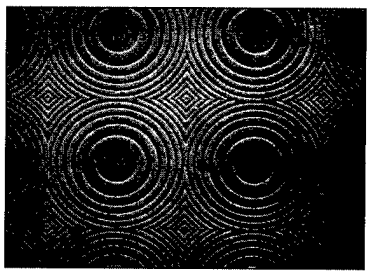
Properties	Applications
■ Low-cost manufacture ■ Molding to near net shape ■ Excellent light transmission (UV to near-IR) ■ Low cation (positive ion) content ■ Low water content	■ Aspheric optics ■ Beamsplitters ■ Microlens arrays ■ Diffractive gratings ■ Fresnel lenses ■ Prismatic arrays ■ Diffractive optics

How the Sol-Gel Process Works

The sol-gel process produces pure silica by mixing silicon alkoxide with water. The alkoxide chemically reacts with water to produce a suspension of colloidal silica-based particles, called a "sol." The sol has a viscosity only slightly greater than water, so it can easily be molded into complex shapes.

In GELTECH's process, the chemical reactions that transform the liquid sol into a rigid gel occur at room temperature and atmospheric pressure. In contrast, other processes occur at high temperature and pressure, which can weaken the material.

The resulting silica has good structural strength and can withstand high temperatures. Furthermore, the process can mold both types of silica: porous and dense.



Above *A scanning electron microscopy photograph of a binary lens array made of GELTECH's dense silica. Using sol-gel processing technology developed for the BMDO SBIR program, GELTECH markets porous silica glass, high-purity silica powders, and custom-made dense silica optics.*

AlBeMet™ Gives Disk Drives Competitive Edge

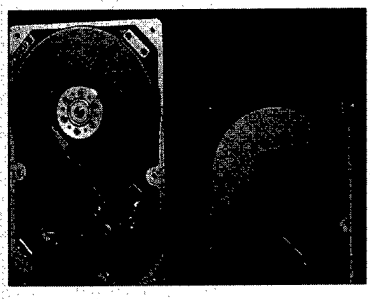
Brush Wellman, Inc.'s (Cleveland, OH) patented process for producing aluminum beryllium alloys has found widespread commercial use in computer disk drive arms. This alloy, marketed under the trade name AlBeMet™, eliminates a major barrier to the use of beryllium materials. Beryllium provides one of the best known combinations of high strength and light weight; unfortunately, it is also one of the most difficult and expensive materials to produce. Brush Wellman's alloy, though, has retained many of beryllium's advantages with the added benefit of a low-cost manufacturing process. This production technique uses material processing equipment based on earlier equipment developed for BMDO.

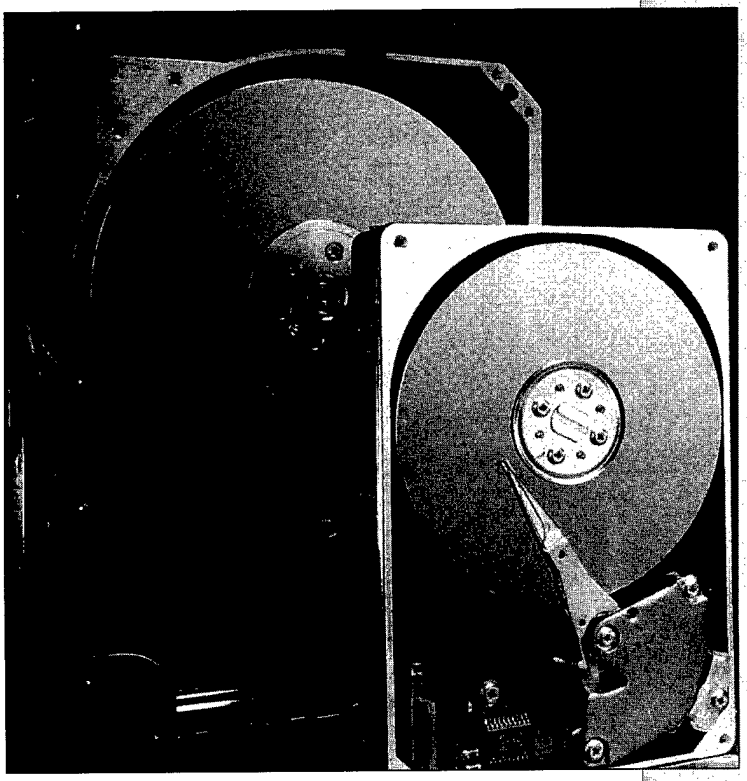
Brush Wellman's Applications Development Center (Fremont, CA) also has teamed with bicycle manufacturers to sell beryllium bicycle frames. The beryllium bicycle frame weighs only 2 pounds, compared to 4 pounds for aluminum and 5 pounds for steel. Ultimately, AlBeMet™ will be used to make bicycle frames.

Sporting goods provide a lucrative market for AlBeMet™, where its light weight and high strength could provide the competitive edge in sailboat fittings, golf club shafts, tennis rackets, and camping goods. In transportation, AlBeMet™ could save weight in cars, trucks, boats, commercial aircraft, and wheelchairs. Other uses include heat sinks in avionics or electronics, paper mill rollers, telescope structural components, and aerospace structures.

AlBeMet™ Properties

AlBeMet™ combines the low density and high stiffness of beryllium with the toughness, ductility, ease of manufacture, and low cost of aluminum. The alloy has up to three-and-a-half times the stiffness-to-weight ratio as aluminum alone. With these properties, the alloy can improve system weight and efficiency; also, its high thermal conductivity can effectively remove heat and increase an electrical system's lifetime.





Right *Computer disk drive arms made of AlBeMet™. Due to its light weight and high strength, sporting goods and transportation products also provide a lucrative market for AlBeMet™.*

Ohio Firm Marketing Structural Composites

Applied Sciences, Inc. (Cedarville, OH) is marketing a process that makes stronger structural composites for aerospace structural components, brakes, centrifuge rotors, flywheels, helicopter blades, and nose cones. When compared to conventional materials, this technique produces materials that are less complex, less expensive, and higher quality. Because the technique can produce lightweight materials for BMD systems, the BMDO SBIR program funded this research at Applied Sciences.

Also Developing Diamond Coating Technology

In another BMDO SBIR contract, Applied Sciences has developed a chemical vapor deposition (CVD) process for making synthetic diamond fibers at a low temperature and pressure. In the near term, Applied Sciences plans to market the diamond fibers for heat sinks and structural composite applications. The company is also developing methods to dope diamond with boron or phosphorus to make it a semiconductor. When doped, diamond would have the highest hole mobility and the second highest electron mobility of any semiconductor. Furthermore, diamond can withstand extremely high temperatures—up to 5,000°F in a non-oxidizing environment—permitting applications in high-temperature integrated circuits, high-power transistors, jet engine sensors, high-power microwave devices, radar, communications, and automotive electronics. Diamond's wide bandgap and high breakdown voltage—15 times that of silicon— also makes high-voltage switches, capacitors, computer-aided tomography imagers, and low-noise ultraviolet and x-ray detectors possible. It can withstand large doses of radiation—20 times more than silicon dioxide—opening up electronic applications in space and nuclear power plants.

Composite Manufacturing at Applied Sciences

Applied Sciences produces reinforced composites by growing catalytic-carbon fibers within a skeleton known as a 3-D preform. The 3-D preform is made by vapor-depositing graphitized carbon on a carbon foam substrate. The resulting structure looks like a graphite honeycomb. After machining the honeycomb to net shape, it is reinforced with carbon fibers.

Applied Sciences can make these composite preforms denser using conventional matrix materials, such as epoxy, pitch, carbon, ceramics, or aluminum matrices. These composite preforms show high stiffness-to-weight and good strength-to-weight. They also readily conduct heat and electricity. Furthermore, Applied Sciences' process is easier and cheaper than 3-D weaving, which is difficult when using brittle, thermally conductive fibers.

Above *An optical micrograph of diamond fibers made at Applied Sciences, Inc. These diamond fibers can reinforce composites used in aircraft skins, turbine blades, engine components, and ceramic armor. When used to make heat sinks, the diamond fibers also can allow electronic devices to run at higher power, higher frequency, and greater speed.*


ENERGY

Auburn University - Page 74

Just as it takes energy to run your car or power your lights, it takes energy to power a railgun used to destroy ballistic missiles, or a satellite used to detect those missiles. While each use has unique needs—whether it consumes a lot of power at once or a little over a long time—all these systems need to be more efficient. Increased efficiency gives us smaller power bills, a cleaner environment, and—in the case of BMD systems—more compact missile defenses.

Deals

Supercapacitor Advance Fosters Joint Venture, Electric Vehicle Research

Maxwell Laboratories, Inc. (San Diego, CA) has signed a licensing agreement with Auburn University (Auburn, AL) to develop, manufacture, and market double-layer capacitors that can store 10 times more energy than the best electrostatic capacitors now available. Auburn University's Space Power Institute (SPI) developed these capacitors for BMDO to power lasers, railguns, and other weapons systems.

Since joining forces, Maxwell and Auburn have won a Department of Energy contract to develop capacitors for electric vehicles. Double-layer capacitors could help eliminate the two biggest flaws of electric vehicles: lack of range and poor acceleration. In an electric vehicle using capacitors, a battery would still be used for cruising; but capacitors—because they release energy much more quickly than batteries—would kick in whenever the car needs to accelerate for merging, passing, emergency maneuvers, and hill climbing. Traditional capacitors can augment battery power for about 2 seconds, while the double-layer capacitor can provide acceleration power for 10 to 15 seconds. Since acceleration rapidly depletes battery charge, capacitors would also increase range by reducing power demands on the battery.

Capacitors also allow electric vehicles to employ regenerative braking technology to increase their efficiency. In regenerative braking, some of the mechanical energy used in braking is converted into electricity, rather than allowing it to dissipate in the form of heat. Since the electrical power surges generated from this process would damage a battery, capacitors must serve as a storage buffer before recharging the battery.

As part of their agreement, Maxwell has opened an R&D facility in the City of Auburn's Center for Developing Industries incubator. Maxwell also has assigned two scientists to work at the facility, both of whom will work with Auburn's SPI to make and evaluate capacitor prototypes. If research proceeds as expected, Maxwell will later establish a capacitor manufacturing facility in Auburn.

Besides electric vehicles, double-layer capacitors can power industrial lasers, pulsed-light generators, and magnetic-forming machines. Someday, they may also replace traditional capacitors now used in computers, telephones, air conditioners, and many other electrical devices.

continued on next page

Left and Right *Researchers at Auburn's Space Power Institute preparing the porous carbon-metal composites used to make supercapacitors. With a high electrical conductivity and high surface area, these composites are used to make supercapacitors that could augment battery power in electric vehicles for 10 to 15 seconds during acceleration, compared to 2 seconds for traditional capacitors.*

Capacitors Are Just the Beginning

Auburn's technique for producing carbon-metal composites allows researchers to develop materials with a combination of properties that could not be merged until now. For instance, the material can combine high surface area with high electrical conductivity or high surface area with a porous, chemically nonreactive structure. As a result, Auburn is exploring many other uses of the material, such as:

■ ***Filtration***

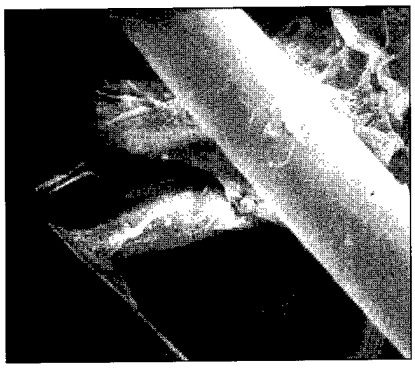
The composite's high surface area, combined with a porous, chemically nonreactive structure, makes it an ideal filter. Possible filtration uses of the composite include building ventilation systems, space station life support systems, blood filtration prior to transfusion, or filtration of beer during brewing. The Auburn Space Power Institute has granted Memtec-America, Inc. an exclusive license to use the carbon-metal composite for filtration applications and a nonexclusive license to manufacture the composite for commercial sale. ➠

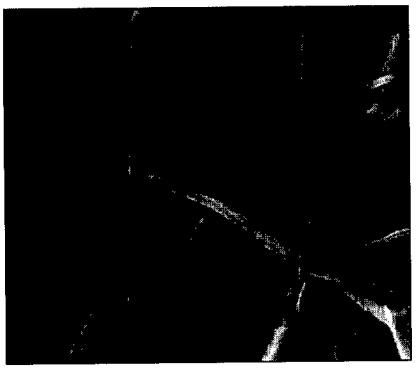
Porous Carbon-Metal Composite Boosts Supercapacitor's Power

In general, a capacitor stores energy by accumulating electrical charge between two conducting plates that are separated by an insulating material. One method to increase a capacitor's storage capacity is to increase the plates' surface area. Auburn SPI researchers have done this with a porous carbon-metal composite that has a surface area of about 1,000 square meters per gram of carbon. To make the composite, the researchers bond high-surface-area carbon fibers to high-conductivity metal fibers—two materials that previously could not be made to bond. These two fibers form an interlocking composite network that has both high electrical conductivity and high surface area.

Storage capacity can also be increased by decreasing the distance between the plates and increasing the dielectric constant of the insulating material. In double-layer capacitors, an electrode and an ionically conducting solution serve as the conducting "plates." At the interface between the electrode and the solution, the solution's molecules align their plus and minus charges to offset charge that has accumulated on the electrode. In this way, charge is aligned as in a traditional capacitor. The interface between the carbon electrode and the solution is typically around 10 ångströms thick. As a result, this technique minimizes the distance between the "plates" to increase the amount of stored energy.

With these qualities, double- layer capacitors can store large amounts of energy in a small volume. A 15 cubic centimeter double-layer capacitor, about the size of a jewelry box is rated at about 6.0 farad capacitance and 5.5 volts. With such a rating, it could power a portable welder that would melt several ounces of lead in a second.





Above and Right *Optical micrographs showing the structure of Auburn's carbon-metal composite. Auburn's technique for making this composite allows researchers to develop materials with a combination of properties that could not be merged until now. This has led to a wide range of uses in filtration, biochemistry, and electrical power storage and generation.*

■ ***Particulate Support***

Because it is highly porous, the composite can contain particles within its matrix structure. In many biochemical processes, a fluid must pass through a bed of packed powder. By separating the powder into individual particles, the composite matrix allows better contact between the fluid and the powder without causing the fluid pressure to drop as it would in passing through a loose powder. The composite is also an ideal site for growing cells and microbes, since the microbes do not have to stack on top of each other as in a thick-layer support. Without this stacking, more microbes receive oxygen and fewer microbes die. Since the structure is chemically inert, the composite could be reused for multiple experiments simply by cleaning and sterilizing it. Possible uses for the composite in this area include bioremediation of polluted soil and pharmaceutical growth. The same concept of entrapped powders also works for heterogeneous catalysis. About 20 percent of the U.S. Gross National Product comes from manufacturing processes that would benefit from improvements in this process.

■ ***Electrode Structures***

Because the composite has high surface area and electrical conductivity, it can be used in electrode structures for high-power batteries and fuel cells. The Auburn Space Power Institute is currently investigating these applications of the composite under BMDO funding.

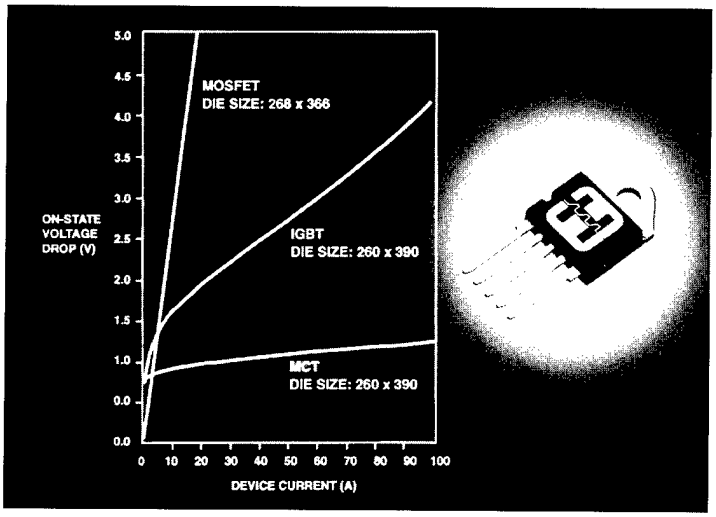
MOS-Controlled Thyristors Help U.S. Regain a Power Electronics Foothold

Harris Semiconductor's (Schenectady, NY) new line of power semiconductors could help re-establish a strong U.S. presence in the high-power semiconductor market, which is now dominated by Japanese and European companies. These devices, MOS-Controlled Thyristors (MCTs), offer better performance than other power semiconductors at competitive prices. Due to the MCT's long list of uses, *R&D Magazine* gave Harris Semiconductor its R&D 100 award for one of the 100 best new products of 1993.

MCT technology could eliminate the need for mechanical transmissions in large electric-drive engines in locomotives and industrial equipment. MCTs offer higher efficiency and lighter weight than standard mechanical systems, thereby saving fuel. Converting from constant-speed motor coupling with mechanical systems to MCT-based adjustable motor drives could, in some processes, save up to 30 percent of total system energy. MCTs also can act as a power conditioning, fault isolation, or regulation system in solid-state circuit breakers, electric transportation, propulsion, jet engine controls, lighting systems, and variable-speed motor drives.

BMDO funded development of MCTs at the General Electric Company to provide power control for accelerators and other directed energy weapons; additional funding for the project came from NASA, the Advanced Research Projects Agency, and the Electric Power Research Institute.

Harris Semiconductor now owns all MCT rights, which the company acquired after purchasing the General Electric power electronics division. Harris introduced its first MCT product—a 600-volt p-type MCT—in September 1992, and its second product—a 65 ampere, 1,000-volt p-type MCT—in early 1993. Other MCT products should follow shortly.



Above *Harris Semiconductor's MOS-Controlled Thyristor (MCT) and a chart comparing its current-carrying capacity to competing power semiconductors. This chart shows that the MCT can carry more current per volt and has less electrical loss due to resistance.*

How the MCT Works

The thyristor is a semiconductor rectifier (a device that controls the flow of current). Unlike the diode, which is a simple rectifier with two power terminals that permit current flow in one direction only, the thyristor uses a third terminal to control the flow of current. The third terminal in the thyristor, the gate, switches current on and off. Once on, the thyristor serves as a variable switch by regulating current flow with a technique known as phase control. To turn off (and stay off), standard thyristors must wait until the current reverses.

By incorporating a metal-oxide-semiconductor (MOS) gate, the MCT improves thyristor performance and adds the valuable capability of gate-controlled turn-off. Individual MCT devices can handle up to 1,000 volts at more than 100 amperes. Further development could lead to individual devices that can handle 2,500 or 4,500 volts at 100 to 200 amperes, and up to 1,000 amperes if paralleled in modules.

MCTs are more rugged, reliable, and efficient than conventional power semiconductor devices. They can operate at higher temperatures, and ultimately permit faster switching speeds than conventional devices (such as the silicon-controlled rectifier [SCR], the insulated gate bipolar transistor [GBT], and the gate turnoff [GTO] device).

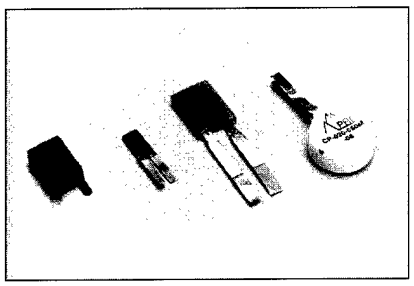
Ultracapacitors: No More Need to Compromise

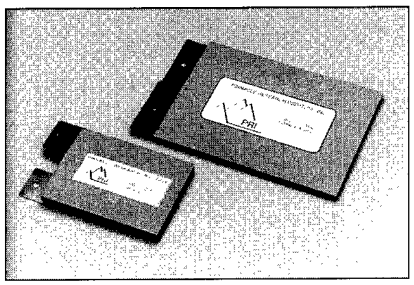
In producing and storing electrical power, designers usually must compromise between providing strong bursts of power (high specific power) and powering devices for sustained periods of time (high specific energy). However, a variation of the capacitor, called an ultracapacitor, can provide high specific energy and power. Pinnacle Research Institute, Inc., or PRI (Los Gatos, CA), developed the ultracapacitor with early funding from the BMDO SBIR program and later support from other defense organizations.

Ultracapacitors have already been demonstrated for military applications, such as in electronic fuze applications in Operation Desert Storm. PRI also has received funding from numerous commercial sources and the Electric Power Research Institute. In one commercial project, PRI has developed ultracapacitors that drive handheld power tools used in orthopedic surgery, which should be commercially available by 1995. PRI has also developed an ultracapacitor for use in automobile air bags. Currently, the power source for air bags is about the size of a thumb, while the PRI ultracapacitor is smaller than the pinky's fingernail.

PRI has also received a contract with the California Air Resource Board to produce ultracapacitor prototypes for electrically heated catalytic converters in automobiles. Electrically heated catalytic converters are needed to reduce emissions generated when starting automobiles. California will require that automobiles sold in the state have electrically heated converters by 1998. Eleven other states have also mandated this requirement.

Ultracapacitors also could provide backup power for computers, boost electromagnetic launchers, serve as cardiac defibrillators, and power airplane deicers. Furthermore, they could be incorporated into hybrid vehicles, which require both small internal combustion engines and battery systems to climb hills and accelerate.





Above *Pinnacle Research Institute's ultracapacitors. With the ability to provide high specific power or high specific energy, the ultracapacitor has a wide range of commercial and military uses.*

How Does the Ultracapacitor Work?

The ultracapacitor stores charge within electrode plates that have a surface coating of metallically conductive ceramic. The device operates by an electrochemical double layer (sometimes called the Helmholtz layer) where energy is stored by ionic separation. Dipoles of positive and negative ions are oriented along the surfaces of oppositely charged electrodes. As energy is released, this orientation relaxes back to a disorganized state of the bulk electrolyte.

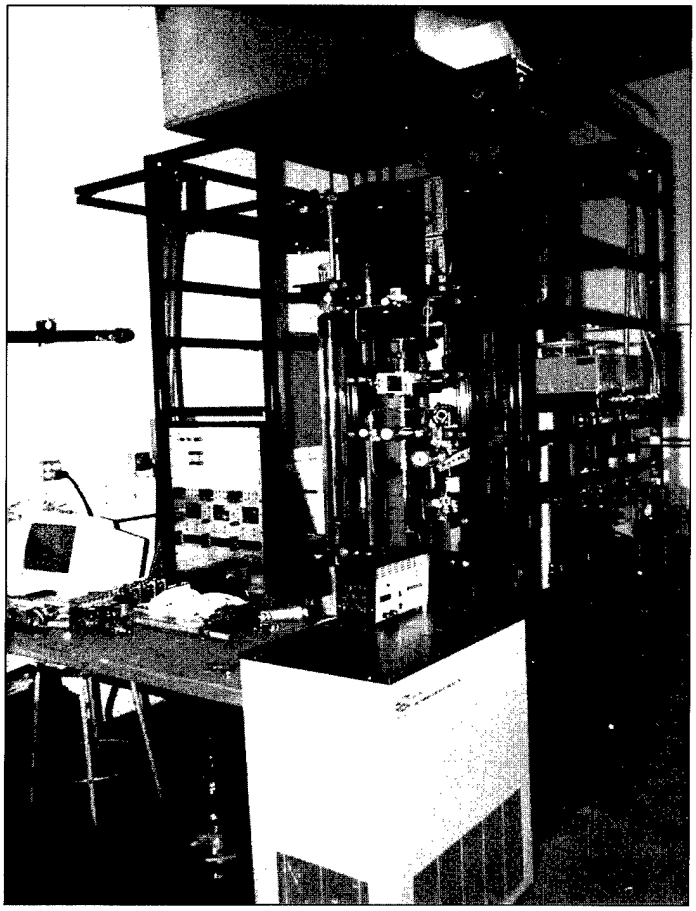
Unlike batteries, there is no chemical reaction; therefore, the ultracapacitor can conceivably be discharged and recharged an indefinite number of times. Furthermore, its sponge-like surface gives the plate an actual surface area that is 100,000 times greater than the surface area of the same plate if it were smooth. The higher surface area allows more energy to be stored.

With this design, the ultracapacitor allows nearly instantaneous recharging. The system also has 100 times more power per ounce than most capacitors, and electricity is stored virtually forever. Moreover, the ultracapacitor is much smaller than conventional capacitors—for many applications, it is smaller than a nickel. Most important, PRI's second-generation ultracapacitors should be able to release large amounts of energy gradually. With this advance, ultracapacitors could serve as a complete battery system in electric vehicles, as well as other applications that require both occasional power bursts and continual moderate energy release over a long time.

BMD Research Helps Introduce Environmentally Friendly Refrigerators

After patenting a thermally driven heat pump, Rocky Research Corporation (Boulder City, NV) sold a license option to an appliance company to develop portable minifridges that cool for up to eight hours without being plugged in. This technology will be partially sponsored on a cost-shared basis by a BMDO SBIR contract to build an efficient, low-maintenance refrigeration system to cool space-based platforms.

Rocky Research's heat pump concept is based on a complex compound solid-gas sorption system (see sidebar). This system uses small, lightweight, and inexpensive equipment with few moving parts and low maintenance. It also has high efficiency and low operating cost, and can be easily scaled to large cooling capacity systems. As a result, Rocky Research's sorption compressor could replace vapor compression cooling systems now used for commercial and consumer refrigeration and air conditioning.



Above *Rocky Research Corporation's solid-gas sorption compressor. This system uses small, lightweight, and inexpensive equipment with few moving parts and low maintenance. As a result, Rocky Research's sorption compressor could replace vapor compression cooling systems now used for commercial and consumer refrigeration and air conditioning.*

Complex Compound Refrigeration Generates Efficiency Gains

Over the last 50 years, cooling, heat pump, and refrigeration systems have relied on vapor compression technology. Vapor compression requires large investments in electric sources to cover power needs on hot days, while the cost of generating electricity is increasing due to the cost of meeting environmental regulations. In addition, alternative refrigerants are now needed due to concerns over the ozone depleting potential of chlorof-luorocarbons (CFCs). New refrigerants developed to date decrease the efficiency of vapor compression systems.

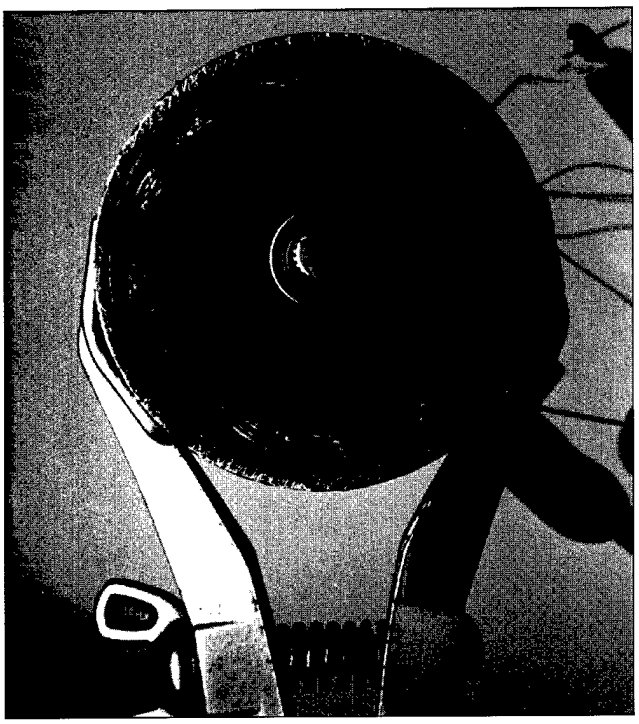
Rocky Research's thermally driven heat pump does not use CFCs and provides efficient, low-cost cooling. The heat pump uses complex compounds that consist of an inorganic metal salt and a vapor. In the evaporation cycle, the salt combines with the vapor to absorb heat and chill an area. The reaction reverses in the condensation cycle and rejects heat exhaust.

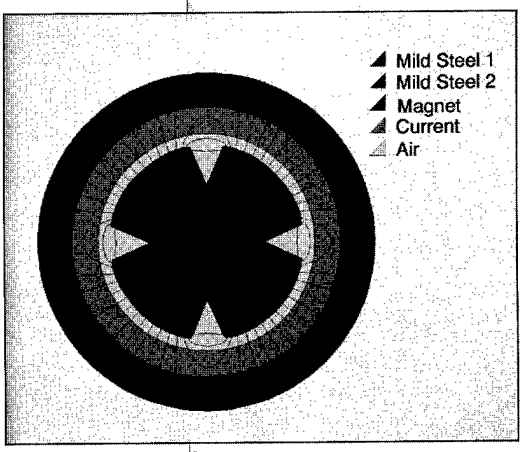
Stronger Magnets Make Smaller, Lighter Motors

Advanced Materials Corporation's, or AMC's (Pittsburgh, PA), direct current motors can deliver 20 percent more torque than comparable commercial motors. These brushless motors also can reduce system weight, provide better control, and increase energy efficiency—giving them promise for commercial use in consumer electronics, power hand tools, electric vehicles, washing machines, and refrigerators.

Seeking a high-efficiency motor to operate beam control equipment, position mirrors, and generate power, the BMDO SBIR program funded development of the motor and the permanent magnets used to power it. These magnets, which have exceptionally high energy products, also show promise for advanced turbines employing magnetic bearings.

So far, AMC has marketed its magnetic materials to some national laboratories and commercial organizations, and the company is bidding for Advanced Research Projects Agency funding to pursue electric vehicle applications of the brushless motor. AMC also is seeking strategic alliances to commercialize its magnets and motor technology.





Above and Right *Advanced Materials Corporation's (AMC's) permanent magnet and a graphic illustrating its magnetic properties. AMC has built direct-current motors with these magnets that can deliver 20 percent more torque than comparable commercial motors. These magnets, which have exceptionally high energy products, also show promise for advanced turbines employing magnetic bearings.*

Rare Earth Materials Provide Stronger Magnets

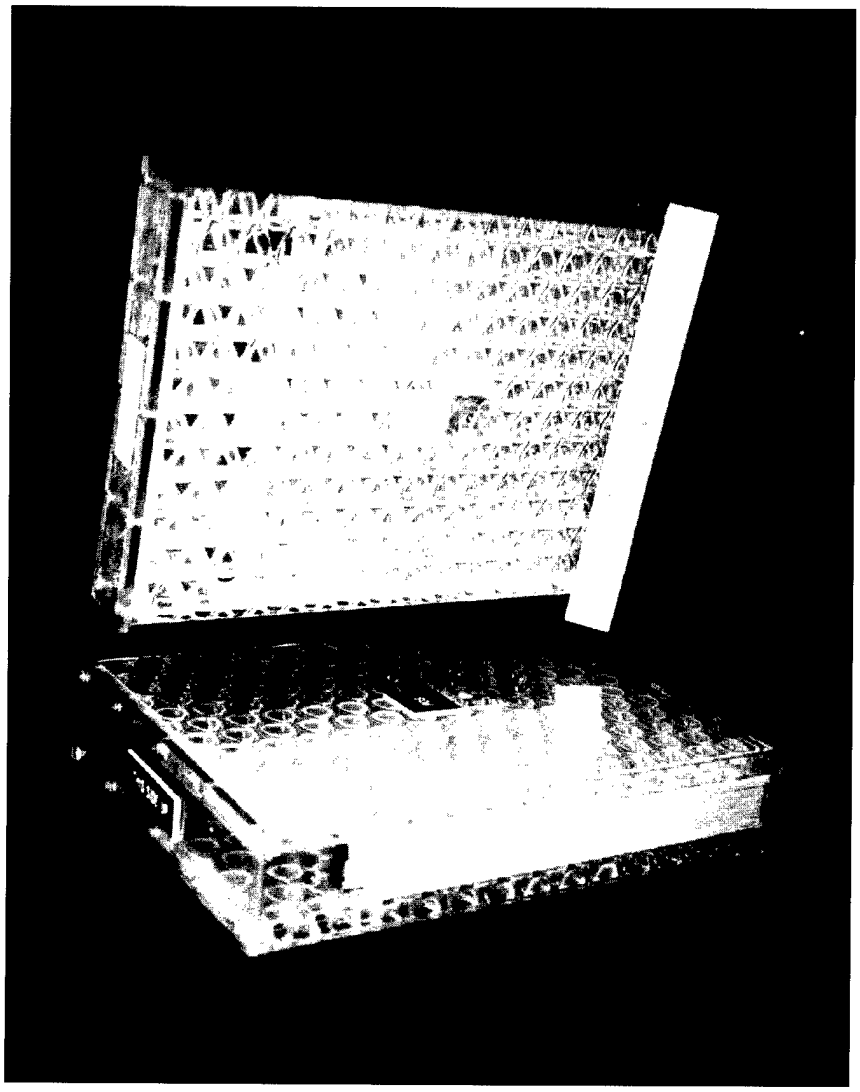
Because the weight of magnetic motors is inversely proportional to the strength of the magnetic field, much of AMC's research focused on increasing the energy product of rare earth iron boron materials—a class of materials that have strong magnetic properties. In particular, this research focused on praseodymium iron boron materials (PrFeB). AMC developed PrFeB magnets with energy products that exceeded 46 million Gauss Oersteds (MGOe)—35 MGOe is considered high—at room temperature and retain strong magnetic properties up to 120°C. At cryogenic temperatures (around 4.2 Kelvin) the magnets have energy products of 50 MGOe, by far the highest energy products achieved at these temperatures.

Motors employing these magnets have more rotational inertia than competing motors, such as the induction motor. As a result, these materials are best suited to motors that operate at a constant speed.

Lead-Acid Battery Shows Promise for Electric Vehicles

The Advanced Battery Group of Johnson Controls, Inc., or JCI, (Milwaukee, WI) is developing lead-acid batteries for use in electric and hybrid vehicles under the Department of Energy's Electric Vehicle Program. JCI developed these batteries, which deliver high specific power for short periods of time (see sidebar), in a joint project with the Jet Propulsion Laboratory (JPL) and Wright-Patterson Research Labs. BMDO funded this research for advanced railgun and laser applications, which require large pulses of power (about a gigawatt) for very short times (a few milliseconds).

JCI has all of the proprietary rights to the technologies developed under this program by virtue of its own inventions and a license from JPL. Therefore, JCI will continue the commercialization process; a new generation of bipolar devices is expected in September 1994.



Above *Johnson Controls, Inc.'s lead-acid battery. First developed for BMDO railgun and laser applications, the battery is now undergoing further development for electric and hybrid vehicles under the Department of Energy's Electric Vehicle Program.*

Bipolar Battery Employs Stacking Technology

JCI's lead-acid battery consists of a stack of bipolar electrodes sandwiched between two end electrode assemblies. Each bipolar electrode, made of a thin conductive plate separating the positive (lead dioxide) and negative (lead) plates of adjacent cells, adds 2 volts to the overall battery voltage. Lighter weight and corrosion-resistant hardware could increase the peak specific power from the current 1.1 kilowatts per kilogram design to 2.5 kilowatts per kilogram over a lifetime of up to 1,000 cycles. The most demanding part of developing this type of battery technology is properly sealing the separate electrodes to prevent electrolytes from intermingling.

The resulting pulsed bipolar batteries are relatively lightweight, compact modular devices. Early prototypes produced a power density of 1.1 kilowatts per kilogram and a total lifetime of up to 1,000 seconds. Improvements in manufacturing procedures could increase this value by a factor of 10 to 10,000. The product design process is directed towards higher power density rather than total energy. Further bipolar battery developments are projected to save 30 to 50 percent in mass and volume over the present bipolar design. This corresponds to a 70 to 90 percent reduction in specific power and energy from conventional lead-acid batteries.

BMD Technology Applications Report

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